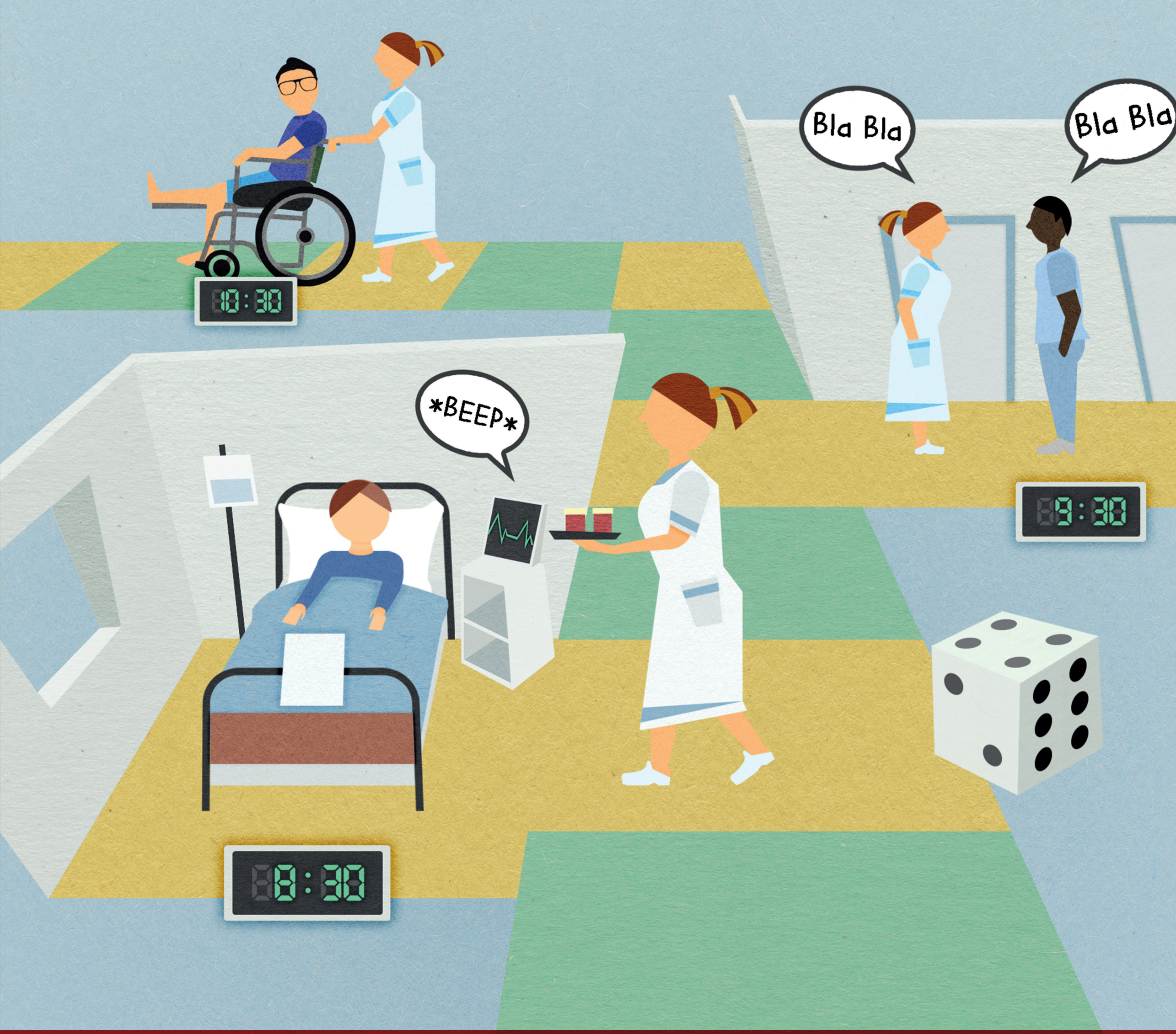
Exploring the effect of the sound environment on nurses' task performance



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AN APPLIED APPROACH FOCUSING ON PROSPECTIVE MEMORY

Jikke Reinten

Bouwstenen 296

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EXPLORING THE EFFECT OF THE SOUND ENVIRONMENT ON NURSES' TASK PERFORMANCE

An applied approach focussing on prospective memory

Jikke Reinten

The work described in this thesis was performed at the research group Technology for Healthcare Innovations which is part of the Research Centre for Healthy and Sustainable living at University of Applied Sciences Utrecht. The work was performed within the IMPULS II SPARK program.

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Summary

Sound is an important physical aspect with the capability of influencing people. This has to be taken into account when making design decisions regarding the built environment. One area in which the effect of the sound environment on its users has received particular research interest is healthcare. Following the concept of evidence-based design, newly built, or refurbished, hospitals, are often based on the Healing Environment principle, defined as “a place where the interaction between patient and staff produces positive health outcomes within the physical environment”.

Research on the sound environment in hospitals typically focusses on patients, and its positive or negative influence on their safety, health or satisfaction. Less attention is being paid to staff members and their performance, which is key in delivering a high quality of care. The performance of nurses plays an important role in patient outcomes and patient satisfaction. In this thesis, the focus is on the effect of sound on the cognitive performance of nurses.

The effects of sound on cognitive performance have been long recognized, but adequate translation of such effects to applied settings is lacking. This can be explained by the focus of the majority of studies on the effect of sound on cognitive performance, which is driven by the goal of understanding the mechanisms responsible for the effects. The experimental tasks that are used in laboratory settings are often relatively ‘process pure’ and have shown to be more sensitive to sound effects than complex, more realistic tasks. Generalizing results of lab studies to the field, however, requires the task to be representative of the complex task in the applied setting. Additionally, sound conditions have to be representative of the conditions these tasks are performed in, and the differences between two experimental sound conditions should be feasible results of realistic interventions.

The work presented in this thesis is the result of an applied exploratory research approach which combines both qualitative and quantitative methods. The main aim was to explore the influence of the sound environment in a hospital on nurses’ cognitive performance and to investigate the effect of realistic measures that can be taken in the context of creating healing environments.

The thesis starts with a review of the literature on the effect of sound on human task performance in **Chapter 2**. In this review, there is a specific focus on the role of room acoustics. In this review, only studies presenting results that are directly translatable to room acoustic design decisions are included. A small number of 12 studies complied with the search criteria, resulting in fragmented information on specific tasks in specific sound environments. This finding emphasized the need for an overall approach to first gain insight in the sound environment, the task and their interaction at a workplace, to identify critical combinations of tasks and sound. These insights could then be used in a dedicated laboratory study that complies with the prerequisites stated before.

This approach, and its application in a Dutch nursing ward are described in **Chapter 3**. Here, an observation study was conducted combining both qualitative and quantitative research methods. Our aim was to simultaneously analyze the sound conditions a nurse was exposed to during a day shift and the activities that took place. Our particular interest, which resulted from an initial observational case, was the forming and retrieving of prospective memory (PM) intentions. An important aspect of a nurses’ job is to carry out intended care activities at the right time, this requires prospective memory. Examples of typical PM tasks in the context of nursing are remembering to administer medication at a specific time or turning a patient every hour.

The results of the observation study are presented in **Chapters 4 and 5**. In **Chapter 4**, the analysis of the sound environment is discussed with a specific focus on distractions. **Chapter 5** presents the analysis of the role of prospective memory. Key findings were the large percentage of the time that nurses are exposed to intelligible background speech while performing the important task of forming prospective memory intentions. Furthermore, it was found that prospective memory failures were the cause of over 40% of the care left undone. These findings motivated an experimental study on the effect of intelligible background speech on the forming and retrieving of prospective memory intentions.

The results of the observation study were used as input for the design of this experiment which is presented in **Chapter 6**. An ecologically valid, complex task was designed to measure the forming and retrieving of prospective memory intentions. The novel experimental task consisted of two parts. Forming intentions while reading electronic medical records and retrieving intentions during a 'virtual shift' in the form of a board game. Nurses were recruited to participate in a within-subjects experimental design. To measure the effect of sound conditions, room acoustic modelling software was used to simulate three realistic acoustic environments. The results indicate that background speech in an acoustically treated room (highly absorbing), and thus having a high intelligibility, impaired the retrieving of PM intentions compared to an ambient (no speech) condition, but also (non-significantly) compared to the same speech in a more reverberant room.

In **Chapter 7**, the approach that was used in this thesis is presented as a generic approach, focusing on its applicability in other settings. A summary of the main findings is presented along with their implications for design decisions in the context of creating healing sound environments. Furthermore, the implications of this project for nursing practice and research on prospective memory are discussed.

Samenvatting

Geluid is een onlosmakelijk onderdeel van de gebouwde omgeving en kan een grote invloed hebben op de mens. Bij het maken van ontwerpbeslissingen voor gebouwen dient hier rekening mee gehouden te worden. Onder andere in de gezondheidszorg wordt veel onderzoek gedaan naar hoe en in welke mate geluid en akoestiek invloed hebben op de gebruikers van een gebouw. Het concept ‘evidence-based design’ wordt toegepast in nieuwe of te renoveren zorggebouwen om een zogeheten ‘helende omgeving’ te creëren. Een helende omgeving wordt gedefinieerd als “een plek waar de interactie tussen patiënt en zorgpersoneel positieve gezondheidsresultaten oplevert ondersteund door de fysieke omgeving”.

Bestaand onderzoek met betrekking tot de geluidsomgeving in ziekenhuizen richt zich met name op patiënten en de invloed van geluiden op hun veiligheid, gezondheid of tevredenheid. Minder aandacht gaat uit naar het zorgpersoneel en de manier waarop geluid hun prestaties beïnvloedt, terwijl dit een belangrijk aspect is in het leveren van goede zorg. In dit proefschrift staat de invloed van de geluidsomgeving op de taakuitvoering van verpleegkundigen centraal. Een goede taakuitvoering door verpleegkundigen is van groot belang voor de veiligheid en tevredenheid van patiënten.

Hoewel de cognitieve effecten van geluid worden onderkend als gevolg van vele laboratorium studies, is de vertaling van deze effecten naar toegepaste omgevingen vaak ontoereikend. Een mogelijke verklaring hiervoor ligt in het specifieke doel van deze laboratorium studies: het begrijpen van de mechanismen die de effecten van geluid veroorzaken. De experimentele taken die gebruikt worden zijn vaak ‘proces puur’ wat wil zeggen dat ze één specifiek aspect van de menselijke cognitie meten. Omdat het effect van geluid sterk taakafhankelijk is, zijn de effecten die gemeten worden bij deze ‘proces pure’ taken niet één op één te vertalen naar meer complexe, meer realistische taken. Om de resultaten van laboratorium studies te kunnen vertalen naar een toegepaste omgeving moet de experimentele taak representatief zijn voor de taak die door een professional wordt uitgevoerd. Daarnaast is het van belang dat de experimentele geluidscondities die gebruikt worden overeen komen met de geluidscondities zoals die in de werkomgeving voorkomen. Ook is het zinvol wanneer de verschillen tussen experimentele geluidscondities het gevolg kunnen zijn van realistische interventies in de praktijk

Dit proefschrift presenteert de resultaten van een toegepaste, exploratieve onderzoeksaanpak waarin kwalitatieve en kwantitatieve methoden gecombineerd worden. Het doel van het onderzoek was inzicht te verkrijgen in de invloed van de geluidsomgeving in een ziekenhuis op de cognitieve prestaties van verpleegkundigen en om het effect van realistische maatregelen te onderzoeken binnen de context van het creëren van helende omgevingen.

Het proefschrift begint met een literatuurstudie naar het effect van geluid op prestaties in **Hoofdstuk 2**. In deze review ligt de nadruk op de mogelijke effecten van ruimte akoestiek. Alléén studies waarvan de resultaten direct vertaalbaar zijn naar ruimte akoestische ontwerpbeslissingen of interventies zijn geïncludeerd. Er werden slechts 12 studies gevonden die voldeden aan de gestelde criteria, wat gefragmenteerde informatie opleverde over hele specifieke taken in specifieke geluidsomgevingen. Deze bevinding heeft aangezet tot de exploratieve aanpak van dit onderzoek, waarbij éérst goed is gekeken naar de geluidsomgeving, de taken en de interactie tussen beide op een werkplek. Dit heeft geleid tot het identificeren van kritische combinaties van taak en geluid waarvan er vervolgens één gemodelleerd is in een laboratorium experiment dat voldoet aan de eerder genoemde criteria.

Deze exploratieve aanpak, toegepast in een verpleegafdeling van een ziekenhuis is beschreven in **Hoofdstuk 3**. De aanpak omvat een observatiestudie waarbij kwalitatieve en kwantitatieve methoden gecombineerd zijn. Het doel van de observatie was om gelijktijdig de geluidscondities waaraan een verpleegkundige gedurende een dagdienst wordt blootgesteld en de activiteiten die plaats vinden te analyseren. In het bijzonder was de aandacht gericht op het vormen en uitvoeren van intenties voor uitgestelde taken. Het op het juiste moment of tijdstip uitvoeren van eerder gevormde intenties is een belangrijk onderdeel van de taak van een verpleegkundige. Het prospectieve geheugen (PM) ligt hieraan ten grondslag. Typische PM taken zijn bijvoorbeeld op het juiste tijdstip medicatie toe te dienen, of een patiënt elk uur om te keren.

De resultaten van de observatiestudie worden gepresenteerd in **Hoofdstuk 4** en **Hoofdstuk 5**. In **Hoofdstuk 4** wordt de analyse van de geluidsomgeving toegelicht en bediscussieerd. De rol van afleiding door geluid staat hier centraal. **Hoofdstuk 5** gaat in op de taakanalyse, met de focus op het prospectief geheugen. Een belangrijke bevinding was het grote deel van de tijd dat verpleegkundigen blootgesteld worden aan verstaanbare achtergrondspraak terwijl ze bezig zijn met geconcentreerde taken zoals het vormen van intenties voor uit te voeren taken op basis van informatie uit elektronische patiëntendossiers. Een andere belangrijke bevinding is dat het vergeten van eerder gevormde intenties de oorzaak zijn van 40% van de niet uitgevoerde taken. Deze resultaten hebben geleid tot de opzet van een experimentele studie naar het effect van achtergrondgeluid op het vormen en uitvoeren van prospectieve geheugentaken.

Het ontwerp en de uitvoering van deze experimentele studie zijn gepresenteerd in **Hoofdstuk 6**. Een ecologisch valide, complexe taak is ontworpen om het vormen en uitvoeren van intenties te kunnen meten. Deze nieuwe experimentele taak bestaat uit twee delen, uitgevoerd in een gecontroleerde ruimte. Tijdens het eerste deel zijn door de proefpersonen (verpleegkundigen) intenties gevormd op basis van een gesimuleerd elektronisch patiëntendossier. In het tweede deel is in de vorm van een bordspel een 'virtuele dienst' doorlopen waarbij gemonitord is of de gevormde intenties op het juiste moment tijdens de dienst zijn uitgevoerd. Om het effect van geluidscondities te meten zijn met behulp van ruimte akoestische modelleer software drie realistische condities gesimuleerd. De resultaten van deze studie impliceren dat achtergrondspraak in een akoestisch absorberende ruimte, resulterend in een hoge spraakverstaanbaarheid, een negatief effect heeft op het uitvoeren van eerder gevormde intenties vergeleken met een geluidsconditie zonder spraak.

In **Hoofdstuk 7** is de aanpak zoals beschreven in dit proefschrift neergezet als een generieke aanpak waarbij de mogelijkheid deze toe te passen in andere omgevingen dan een ziekenhuis wordt bediscussieerd. Ook wordt in dit laatste hoofdstuk een samenvatting gegeven van de belangrijkste bevindingen en de implicaties in de context van het creëren van helende omgevingen. Daarnaast worden de implicaties van de bevindingen besproken vanuit zowel het perspectief van de verpleegkundige praktijk als het onderzoek naar het prospectieve geheugen.

General Introduction

1

1 General introduction

1.1 **Introduction**

Sound is one of the many environmental factors that influence us. This influence ranges from direct physiological changes, such as the destruction of inner ear hair cells when exposed to a very loud noise, to behavioral action: covering our ears. From comforting, such as the safety a child may experience by hearing it's parents speaking softly in the garden on a summer evening, to disturbing, such as the annoyance that same conversation causes at the neighbors who have to get up early the next morning. Sound can affect our mood, our health and our ability to perform a task (Basner et al., 2014).

In turn, we can influence the sound environment. We can decide whether to speak or be silent, we can wear shoes with hard or soft soles, and we can, to a certain extent, decide where and when to carry out activities that produce noise. We can design buildings that shield us from outdoor sound sources and create rooms to perform concentrated tasks. Research on how we are affected by sound provides the opportunity to base design decisions regarding the built environment on knowledge about their impact on its users.

One area in which the effect of the sound environment on its users is of critical interest is healthcare. This was already recognized by Florence Nightingale who wrote in her 'Notes on nursing' that "unnecessary noise is the most cruel absence of care, which can be inflicted either on sick or on well" (Nightingale, 1860). The concept of 'evidence based design' -relating to the effect of design decisions on people- was sparked by a study on the possible influence of the view from a hospital window on recovery time after surgery (Ulrich, 1984). Since then, an increasing number of studies have been published on the effect of features of the built environment on patient outcomes (Iyer, Stein, & Franklin, 2020). The designs of newly built, or refurbished, hospitals, are often based on the 'Healing Environment' principle, defined as "a place where the interaction between patient and staff produces positive health outcomes within the physical environment" (Huisman, Morales, Van Hoof, & Kort, 2012).

The work of nurses plays an important role in patient outcomes and patient satisfaction. Their performance is key in delivering a high quality of care. In the field of ergonomics and cognitive psychology, literature on the effect of the sound environment at the workplace on the performance of tasks is abundant, for reviews see (Beaman, 2005; Szalma & Hancock, 2011). These studies are, however, mainly oriented on office- and factory workers. Studies on the impact of sound on nurses are scarce, both compared to those focusing on patients (Konkani & Oakley, 2012; Morrison, Haas, Shaffner, Garrett, & Fackler, 2003) and to those focusing on other occupations (Ryherd, Okcu, Ackerman, Zimring, & Persson, 2012). Since the hospital is the work environment of nurses, the effect of the hospital sound environment on nurses is an important topic to address in the context of healing environments.

The aim of this thesis is to explore how the sound environment in a hospital influences the task performance of a nurse. This issue is approached from an applied perspective, with a focus on realistic measures that can be taken in the context of creating healing environments.

In this general introduction, the scene is set by providing an overview of the research on healing sound environments in hospitals in general and the effect of sound on nurses. Then, some light is shed on the main mechanisms responsible for the cognitive effects of sound. The chapter is concluded with a section on measuring nurses' task performance and a thesis outline.

1.2 A healing sound environment in hospitals

1.2.1 Effects of the sound environment in hospitals on patients

The main body of research on the sound environment in healthcare focusses on noise levels and their effect on patients (Huisman et al., 2012). The critical effects of noise in hospitals, according to the World Health Organization (WHO), are sleep disturbance, annoyance and communication interference, based on which a guideline value of 30dB(A) L_{Aeq} is suggested for wardrooms[1] (Berglund, Lindvall, & Schwela, 2000). An often cited paper on noise levels in the Johns Hopkins Hospital presents a trend for consistently rising hospital noise since 1960, and expresses concern since none of the reported noise levels comply with the above mentioned WHO guidelines (Busch-Vishniac et al., 2005).

Uninterrupted sleep is important for health and recovery (Ekstedt, Åkerstedt, & Söderström, 2004; Spiegel, Knutson, Leproult, Tasali, & Cauter, 2005). The issue of sleep deprivation due to high noise levels in patient rooms and wards has been long recognized (Wood, 1993) yet is still current (Buxton et al., 2012; Gulam, Xyrichis, & Lee, 2020; Park, M. J. et al., 2014; Yoder, Staisiunas, Meltzer, Knutson, & Arora, 2012). However, evidence on the effectiveness of noise reduction interventions in ward settings is lacking (Garside et al., 2018).

Reviews on noise in hospitals point out the risk for hypertension and ischemic heart disease due to high noise levels (Choiniere, 2010; Konkani & Oakley, 2012). It has to be noted though, that the sources they refer to are related to high occupational noise levels and environmental noise due to (air) traffic which indicate risks due to long term exposure (Lusk, Gillespie, Hagerty, & Ziemba, 2004; van Kempen et al., 2002). Translating such effects to hospital settings, where the target group may be more sensitive, but the duration of exposure cannot be compared to those in work or home settings must be done with caution. Other, somewhat isolated, reported responses to noise are wound healing (in animals) (Wysocki, 1996), pain management (Minckley, 1968), gastric activity (Castle, Xing, Warner, & Korsten, 2007) and hospital length of stay (Fife & Rappaport, 1976).

What becomes clear when reviewing research on the impact of sound on hospitals, is that most studies characterize the sound environment solely based on sound levels. Studies on patient experiences, mostly focusing on sleep disturbance and annoyance, provide some insight on the other, perhaps more meaningful characteristics of the sound environment. In a study performed by Dube et al. (2008), both staff and patients indicated voices, carts travelling in the hall and cardiac monitor alarms to be the most bothersome. Interview results of ICU patients, presented by Johansson et al. (2012) reveal the complexity of subjective experiences of sound. One sound could be disturbing on one occasion but could be experienced as safe and comforting in another. Typical negative experiences, such as fear, helplessness and anxiety were linked to noisy technical equipment or sounds related to the acute treatments of other patients with more severe illnesses.

1 In the new Environmental noise guidelines for the European region, recommendations for hospital noise are not included (World Health Organization, 2018).

This illustrates the importance of looking beyond sound levels when striving to create comfortable and healthy sound environments. Other aspects, such as the content of individual sound events and the frequency in which these events occur for example can be just as important.

1.2.2 Effects of the sound environment on nurses

Published research on the influence of sound on nursing staff is scarce (Blomkvist, Eriksen, Theorell, Ulrich, & Rasmanis, 2005; Ryherd et al., 2012). The central topic in the limited number of found studies is the relation between sound levels and stress, particularly in ICU settings. It has been widely acknowledged that the job of nurses can be very stressful (McVicar, 2003), and according to both nurses' self-report and objective measurements being exposed to high noise levels adds to the stress level. Applebaum et al. (2010) conducted a survey amongst 116 nurses employed at adult medical-surgical units assessing environmental factors, perceived stress, job satisfaction and turnover intention and found that noise was significantly related to job stress. In a neurologic intensive care unit, Ryherd et al. (2008), found that 91% of the nurses felt that noise had a negative impact on their daily work environment. Irritation, fatigue and headaches were experienced by the nurses as a consequence of noise. Morrison et al. (2003) presented positive correlations of noise with measures of stress by measuring heart rate and self-reports of stress and annoyance. Finally, noise-induced stress was found to be positively related to burnout in a survey of 100 critical care nurses (Topf & Dillon, 1988). A cautious comment on the studies that relate measured noise levels to stress in nurses, is the lack of inclusion of confounding factors. When linking measured noise levels to stress in healthcare settings, the factors causing high noise levels may very well be the factors that cause stress, not the noise itself. One publication was identified, an intervention study in a Swedish coronary care unit, that showed improved room acoustics (reduced reverberation time as a result of changing the ceiling tiles) to affect the psychosocial environment in such a way that the staff experienced reduced demands, and less pressure/strain (Blomkvist et al., 2005).

In a study by Mahmood et al. (2011) it was found that high noise levels were indicated by nurses as a 'very important' (27,7%) and 'somewhat important' (31,3%) factor leading to medication errors. Furthermore, reducing noise levels was the second most mentioned solution to reduce errors. Despite this, no empirical studies were identified that objectively relate nursing performance to the sound environment.

A handful of studies was found looking into the impact of sound on other healthcare staff. In Murthy et al. (1995), task performance under noisy conditions was tested in a controlled laboratory setting with anesthesia residents being exposed to recorded operating noise (77 dBA). Their results showed reduced mental efficiency and poorer short-term memory under the noisy condition. Results of a within-subjects study amongst pharmacists, examining the effect of the signal-to-noise (S/N) ratio on the ability to correctly identify spoken drug names have shown that accuracy improved significantly when the S/N ratio improved (Lambert et al., 2010) Another well represented topic regarding sound in hospitals, particularly in intensive care units and operating rooms, is alarm management. A high frequency of alarms, including false alarms, can lead to annoying and unsafe situations due to alarm fatigue (Konkani, Oakley, & Bauld, 2012).

Given that healthcare workers place sound as the third most important design factor, ahead of light (Mourshed & Zhao, 2012), the research attention on this topic is lacking.

1.3 Cognitive effects of sound

As stated above, little knowledge is available on the influence of the sound environment on the performance of nurses in particular. However, in the field of ergonomics, applied acoustics and cognitive psychology, there is an abundance of available material on the cognitive effects of sound. The mechanisms responsible for the effect of sound on human performance have been, and still are, the topic of much debate and research.

Amongst the early studies on the effects of noise on human performance are those conducted by Donald E. Broadbent, who demonstrated changes in vigilance and serial recall tasks as a result of sustained exposure to very high noise levels (100 dB) (Broadbent, 1953; Broadbent, 1954). In the following decades, in the attempt of explaining the mechanisms responsible for the effect, two opposing theories were developed and extensively debated in psychological journals (Broadbent, 1976; Broadbent, 1978; Poulton, 1978). The first theory was based on arousal, which would act as a facilitator at low levels and short exposure, but as an obstructer at high levels and extended exposure (Broadbent, 1978). Another theory suggested that background noise would mask inner speech and thus impair performance (Poulton, 1979). Research concerning these theories was mainly focused on the effects of white noise with varying intensities on performance.

Since then, perhaps driven by the absence of extremely high noise levels in modern day workplaces, research has become more concerned with the characteristics of sound, how they are perceived and processed and how these processes may interfere with the mental activities involved in a task (Smith, A. P., 2012). At the core of these, more recent, studies on the cognitive effects of sound is the irrelevant sound effect, which technically only refers to the impairment of a serial recall task by irrelevant background sounds (Tremblay, Nicholls, Alford, & Jones, 2000).

According to the, now widely accepted, duplex-theory of auditory distraction, there are two mechanisms responsible for auditory distraction: interference-by-process and attentional capture (Hughes, 2014). Interference-by-process occurs, when similar processes are engaged in the automatic processing of the sound environment and in the execution of a focal task, causing interference (Hughes & Jones, 2005; Jones, D. M., Marsh, & Hughes, 2012). For example, performance of a semantic task such as proofreading, a task that requires comprehension of the material, has been shown to be vulnerable to the meaningfulness of speech (Jones, D. M., Miles, & Page, 1990). If the semantic content of the meaningful speech is related to the material that has to be studied, the disruption can be expected to be even more pronounced (Jones, D. M. et al., 2012; Marsh, J. E., Hughes, & Jones, 2008). Performance on a serial short term memory task, however, seems to be impaired by the presence of any sound with acoustical variation between one segment and the next, but not by the semanticity of the background speech (Hughes, 2014).

In the case of attentional capture, a sudden, unexpected, change in the sound environment diverts the attention from the focal task, seemingly regardless of the processes involved in that task (Vachon, Hughes, & Jones, 2012; Vachon, Labonté, & Marsh, 2017). A distinction is made between specific and aspecific attentional capture. Specific attentional capture occurs when features of the auditory event, relevant to the (latent) interest of the listener, temporarily attract involuntary attention (Eimer, Nattkemper, Schröger, & Prinz, 1996). Examples are hearing your own name (Röer, Bell, & Buchner, 2013), or perhaps a discussion about food could speak to the interest of a 'listener' who is very hungry. Aspecific attentional capture occurs when the listener's expectation about the sound environment, which is based on the sound environment in the recent past, is violated. Examples are an alarm or a sudden deviant tone in a repetitive beeping signal (Escera, Alho, Winkler, & Näätänen, 1998; Hughes, Vachon, & Jones, 2007).

1.4 Background speech

Next to the line of studies mainly focused on these mechanisms, there is a growing body of literature addressing the effects of background sound on performance from a somewhat more applied perspective. As background speech is considered to be one of the most annoying environmental factors in workplaces (Banbury & Berry, 2005; Hongisto, Haapakangas, Varjo, Helenius, & Koskela, 2016; Pierrette, Parizet, Chevret, & Chatillon, 2015), these studies mainly focus on the effect of speech with varying intelligibility on a range of cognitive tasks. There is converging evidence that a higher degree of speech intelligibility leads to a higher performance impairment, for reviews see (Hongisto, 2005; Liebl & Jahncke, 2017). The concept of a larger effect on performance with increasing intelligibility of irrelevant speech fits well in the duplex-mechanism view. A higher acoustical variation between auditory segments, which corresponds with a higher speech intelligibility, has a higher potential to interfere with ordering processes involved in a cognitive task. In the case of a semantic task, which has been shown to be vulnerable to meaningful speech, a lower speech intelligibility (below a certain threshold) could reduce or eliminate the automatic processing of background speech and therefore the effect on performance. It is unclear, however, what happens in the case of background speech with only a slightly decreased intelligibility. A model suggested by Hongisto (2005) shows a sigmoidal curve, that predicts a steep decay of task performance when the intelligibility of background speech, measured by the Speech Transmission Index (STI) (Steeneken & Houtgast, 1980) is between 0.2 and 0.6. According to this model, background speech with a STI value of 0.6 or higher, which can be considered a good to excellent intelligibility, strongly impairs performance. Background speech with a STI below 0.2, which can be considered a bad intelligibility, has no effect on performance.

1.5 Nurses' task performance

A nurse's performance is a broad concept that can be measured in various ways and various scales. Considering the scope of this project, the influence of sound on nurses' task performance, it is key to address those aspects of a nurse's job that are critical to their overall performance and are, potentially, affected by sound. From the knowledge that is available on the effects of sound on task performance in general, an obvious direction would be to explore further those aspects that are related to the cognitive work of nurses. Therefore, in anticipation of the work presented in **Chapter 3** of this thesis, this introductory text briefly touches upon the specific cognitive aspect of a nurse's job that became the focus of this project, prospective memory (PM).

Nurses working in a hospital ward have to be able to plan care, prioritize and carry out intended activities at the right time (Ebright, Patterson, Chalko, & Render, 2003; Potter et al., 2005). Failing to carry out planned care activities constitute as an error of omission, or missed care, which has the potential to affect patient outcomes and work satisfaction. (Kalisch, Tschannen, & Lee, 2012; Lake, Germack, & Viscardi, 2016; Tschannen, Kalisch, & Lee, 2010). Missed care can be the consequence of a decision to prioritize other tasks, or due to forgetting. In this thesis the focus is on the latter, forgetting. Prospective memory (PM) is the cognitive ability required to remember to carry out intended activities at an appropriate point in the future (McDaniel & Einstein, 2007). PM tasks are part of everybody's daily life. Imagine brushing your teeth in the morning with the last bit of toothpaste. In this situation, you might form the intention to buy new toothpaste in the grocery store on your way home from work. To successfully complete this PM task, you would have to think about the toothpaste when you are at the grocery store. Examples of PM tasks in nursing are remembering to administer medication at the right time, or remembering to turn a patient every hour. The concept of PM in nursing has been relatively unexplored, as has been the possible influence of environmental factors such as sound.

Further elaboration can be read in **Chapter 3,** in which the decision to focus on this specific aspect is substantiated through the results of an observation case in a hospital ward.

1.6 Aim and outline of the thesis

The main aim of this project is to explore the influence of the sound environment on nurses' task performance and to investigate the effect of realistic interventions. As described in the previous section, our focus is on nurses' PM performance. Gaining insight in the role of PM in nursing can be regarded as a secondary aim of this project.

The work presented in this thesis is the result of an applied exploratory research approach which combines both qualitative and quantitative methods. The starting point of this research was an extensive review of the literature, which is presented in **Chapter 2**. Here, the effect of sound on human task performance is reviewed with a specific focus on the role of room acoustics. In this review, only studies presenting results that are directly translatable to room acoustic design decisions were included. In the discussion of the limited number of studies that complied with the search criteria, the difficulty of generalizing findings to other settings, such as hospitals, was shown, emphasizing the need for applied and dedicated research.

Based on the analysis of the results in **Chapter 2**, a conceptual framework was developed that guided the exploration on the effect of the hospital sound environment on nurses' task performance. An important part of this exploration was gaining insight in the typical sound environment that nurses are exposed to and which cognitive tasks are representative for their daily work.

An approach was developed to simultaneously gain insight in the sound environment, the task (PM) and their interaction in a Dutch nursing ward, which is presented in **Chapter 3**. Here, an observation study was conducted, resulting in both qualitative and quantitative data. The results of the observation study are presented in **Chapters 4 and 5**. In **Chapter 4**, the analysis of the sound environment in a nursing ward is presented with a specific focus on distractions. In **Chapter 5**, the analysis of a particular cognitive task of a nurse, forming and retrieving prospective memory intentions is presented. The results of the observation study are used for the design of a novel experimental task which is presented in **Chapter 6**. The controlled lab experiment was conducted with nurses to investigate the impact of background speech and room acoustics on the forming and retrieving of prospective memory intentions. It was aimed to use an experimental task and experimental sound conditions with a high ecological validity.

In **Chapter 7**, the approach that was used in this thesis is presented as a generic approach, focusing on its applicability in other settings. A summary of main findings is presented along with their implications for design decisions in the context of creating healing sound environments. Furthermore, the implications of this project for nursing practice and research on prospective memory are discussed.

2

The indoor sound environment and human task performance: a literature review on the role of room acoustics

2 The indoor sound environment and human task performance: a literature review on the role of room acoustics

A substantial amount of studies have addressed the influence of sound on human performance. In many of these, however, the large acoustic differences between experimental conditions prevent a direct translation of the results to realistic effects of room acoustic interventions. The review presented in this chapter identifies those studies which can be, in principle, translated to (changes in) room acoustic parameters and adds to the knowledge about the influence of the indoor sound environment on people. The review procedure is based on the effect room acoustics can have on the relevant quantifiers of the sound environment in a room or space. 272 papers containing empirical findings on the influence of sound or noise on some measure of human performance were found. Of these, only 12 papers complied with this review's criteria. A conceptual framework is suggested based on the analysis of results, positioning the role of room acoustics in the influence of sound on task performance. Furthermore, valuable insights are presented that can be used in future studies on this topic. While the influence of the sound environment on performance is clearly an issue in many situations, evidence regarding the effectiveness of strategies to control the sound environment by room acoustic design is lacking and should be a focus area in future studies.

This chapter is based on:

Reinten, J., Braat - Eggen, P. E., Hornikx, M. C. J., Kort, H. S. M., & Kohlrausch, A. G. (2017). The indoor sound environment and human task performance: A literature review on the role of room . *Building and Environment*, *123*, 315-332.

2.1 **Introduction**

People working indoors are continuously subjected to sound. Whether working alone in a private office, or amongst a large number of colleagues in an industrial setting; a complete absence of sound never occurs. Conversations of colleagues, loud industrial noise or the continuous hum of HVAC installations can be distracting (Kjellberg, Landström, Tesarz, Söderberg, & Akerlund, 1996), cause stress (Leather, Beale, & Sullivan, 2003), fatigue (Tesarz, Kjellberg, Landström, & Holmberg, 1997), or even hearing loss (Rabinowitz, 2000), all of which might result in a decrement of task performance. Sound though, can also be stimulating or cause a positive mood change which might in turn result in a performance increase (Thompson, Schellenberg, & Husain, 2001). Already in the early 20th century, studies on the relation between sound and people's performance were conducted (Laird, 1933), and the increasing popularity of open-plan offices in recent years has boosted this field of research (Al Horr et al., 2016).

The substantial amount of research dedicated to the effect of sound on human performance mainly originates from a cognitive psychology point of view. For example, many studies are performed in which people's susceptibility to distraction by noise is used to understand the processes in the human brain (Sörqvist, 2015). The results of these studies are then introduced as evidence to support psychological theories about selective attention (Smith, A. P., 1991), interfering processes (Marsh, J. E. et al., 2008; Marsh, J. E., Hughes, & Jones, 2009) and arousal (Broadbent, 1980). Building on the increasing knowledge about the impact of sound on performance, the current review takes a complementary perspective. Rather than focusing on understanding cognitive processes, we are taking a room acoustic point of view following the working principles of evidence-based building design (van Hoof, Rutten, Struck, Huisman, & Kort, 2015). Furthermore, the scope of this study is limited to the effect of natural sound sources occurring in working environments on task performance. We consider this an important step in defining the prerequisites of a good indoor environment, a topic for which the awareness of its importance has grown in recent years (Chraibi et al., 2016; Huisman et al., 2012). A good sound environment should not lead to any physical, physiological or psychological changes in a person's body that could negatively affect his or her health. Furthermore, the sound environment should allow a person to be in, or should even contribute to obtaining, the most suitable state of mind for a specific activity. What we consider to be lacking in the literature is an overview of the effect of sound on human performance which can be, in principle, translated to room acoustic parameters and adds to the knowledge about the influence of the built environment on people. While letting a person perform a serial recall task when being subjected to either speech at 85 dB(A) or 'silence' in a laboratory experiment (for an example see (Colle & Welsh, 1976)) does provide insight in cognitive processes, it does not help define guidelines for an optimal acoustic (working) environment. These extreme levels are not representative of natural working conditions; moreover, room acoustic interventions or design decisions alone would not allow to realize such large differences between conditions. The question arises to what extent the current body of evidence on the effect of sound on task performance can be used to gain insight in the role of room acoustics.

The present chapter reviews to what extent the current evidence on the effect of sound in the work environment on human performance can be used to aid room acoustic design decisions. To answer this question, it is desirable to clearly specify what effect (passive) room acoustics can have on the relevant quantifiers of the sound environment in a room or space. Based on this, the results can be identified of those experimental studies in which the difference between experimental conditions can, in principle, be attributed to room acoustic modifications. A secondary objective of this review is to derive implications for future research from the results. The meta-analytic synthesis conducted by Szalma and Hancock (2011) in which the results of 151 papers on the effect of sound on human performance were reviewed will form the starting point in the search for literature.

2.2 Search strategy and selection of papers

2.2.1 The effect of room acoustics on the indoor sound environment

For this review's purpose, sound level and speech intelligibility are considered the most important quantifiers of the sound environment that are affected by room acoustics and for which the effect on human performance has been investigated and published. Inclusion and exclusion criteria for the selection of papers which do not take room acoustics into account are based on a theoretical approach of the maximum effect of room acoustics on these quantifiers. Other effects of acoustics on the sound environment, such as the existence of a flutter echo which can make one's own voice sound unnatural and uncomfortable, or a change in the spectral distribution of sounds due to frequency specific sound absorption, are too dependent on the source type and the positions of source and receiver, and will therefore be considered to be outside the scope of this review. Studies on the effect of actual room acoustic changes are included.

The inclusion and exclusion criteria that are used to select articles are shown in Table 2-1. The following sections provide a motivation for the inclusion criteria related to sound levels and speech intelligibility and an explanation of the review procedure.

2.2.2 Motivation for the inclusion criteria related to sound levels and speech intelligibility

2.2.2.1 *Reduction of overall sound level in a room of a fixed size due to sound absorption*

Replacing a sound reflecting ceiling with a ceiling with a high sound absorption coefficient, adding wall panels or absorbing elements in the room and the use of soft furnishings are typical ways to increase the total amount of sound absorption. The sound pressure level difference due to adding sound absorbing material to a room, assuming a diffuse sound field, can be calculated by using the following formula (1). The total amount of room absorption area in m^2 before (S_1) and after (S_2) the intervention has to be known. The formula is only valid outside the direct sound field of a source.

$$\Delta L_p(f) = 10log10\left(\frac{S_2(f)}{S_1(f)}\right). \qquad (1)$$

For the purpose of this review the assumption was made that a feasible difference in the amount of absorption area (S) between a fairly reverberant space and a very sound absorbing space is a quadrupling of S at most. From the formula (1) it can be easily deducted that this will lead to an overall sound level reduction of 6 dB. The fact that it is easier to absorb high frequencies than low frequencies is not taken into account here. Therefore, the reduction of sound level in a room due to added absorption is considered to be a maximum of 6 dB. When the sound source is speech, there are however reports of cases in which the sound level reduction after a room acoustic intervention exceeds this physical reduction (Oberdörster & Tiesler, 2008). The explanation can be found in the Lombard effect, which describes the observation that speakers raise their speaking level when the background level increases (Pick Jr, Siegel, Fox, Garber, & Kearney, 1989). Increased vocal output as a function of room absorption in multitalker situations was investigated in an experimental setup (Nijs, Saher, & den Ouden, 2008). Results indicate that, in a multitalker situation, per doubling of the amount of absorption area, the sound level is reduced by 5.5 dB. In the case of quadrupling the amount of absorption the sound level reduction would then reach 11 dB. A maximum difference of 11 dB between control and experimental conditions, in the case of multi-talker speech or informationless background noise, is introduced as one of the inclusion criteria for this review. For other source types the maximum difference between control and experimental conditions is 6 dB, since the Lombard effect does not apply here.

Table 2-1 overview of inclusion and exclusion criteria

Review round	Inclusion	Exclusion
1 Based on titles only		All papers of which the topic was unrelated to sound or acoustics.
2 Based on abstracts only	Study contains empirical evidence on the influence of sound or noise on some measure of human performance. Subjects are between 18-65 years of age (working population). Subjects are healthy, without reported hearing loss.	Indirect effects of sound (health outcomes, performance outcomes as a result of hearing loss). Review papers (no methods included) Papers not published in English.
3 Based on full papers	The difference between the control situation and the experimental situation must be attributable to a passive room acoustic change. This means that the descriptions below apply: The sound source in both control and experimental situation must be of equal origin and behavior. The maximum difference in sound level between control and experimental situations is 25 dB for studies comparing different sound levels of 1 sound source. The maximum difference in general sound level between control and experimental situations is 11 dB for multitalker speech and broadband noise. The maximum difference in general sound level between control and experimental situations is 6 dB for sound sources other than speech and broadband noise.	Studies in which a difference in speech intelligibility is created in a manner that cannot be realized by passive room acoustic interventions. Studies during which the subjects are exposed to sound levels higher than 85 dB(A). Studies in which one sound condition is compared to a completely silent condition. Studies in which an ambient noise condition is compared to a different experimental sound condition. Studies in which an active sound masking system is used.

2.2.2.2 *Reduction of sound level from a single sound source*

Increasing the absorption of a ceiling and placing sound blocking, screening and absorbing elements between a single source and a receiver will increase the spatial decay of sound (Keränen, Hongisto, Oliva, & Hakala, 2012; Wenmaekers & Hak, 2015). This means the effect of sound absorption increases with the distance from the source. The difference in sound level resulting from a single sound source at 4 meters from that source can be as large as 13 dB for two extreme situations (reflecting walls and ceilings, without screens, versus absorbing walls and ceilings and high sound screening and absorbing panels) (Keränen et al., 2012). At 16 meters from the source however, this difference can be as high as 25 dB (Virjonen, Keränen, & Hongisto, 2009). These results are based on a single sound source at a certain distance such as a human voice, a telephone or a machine and do not take into account any other sources in the same room. A maximum difference of 25 dB is introduced as inclusion criterion for studies comparing the effect of a single voice or single sound source. In the case of speech however, the absolute levels at which the speech is presented should be realistic as well. At 1m distance from the speaker, the sound level caused by human speech is approximately 60 dB(A) (Lazarus, 1986), and the absolute levels of speech should be related to the level difference that is introduced.

2.2.2.3 *Speech intelligibility*

The intelligibility of speech is influenced by room acoustics. Reducing reverberation by adding sound absorption will improve speech intelligibility at short source-receiver distances (within the direct sound field) while reducing speech intelligibility at longer distances as a result of a steeper decay of sound level. A common parameter to describe speech intelligibility between a source and a receiver is the speech transmission index (STI), a dimensionless number between zero and one (Steeneken & Houtgast, 1980). A perfect speech intelligibility results in an STI value of 1, whereas a value below 0.3 leads to almost unintelligible speech. Another effect of increasing the amount of absorption in a room is the reduction of background noise which increases the speech intelligibility if the listener is close to the sound source, i.e. when the direct sound dominates the sound heard by the listener over the reverberant sound. This complexity makes it hard, if not impossible, to introduce a range of STI difference as an inclusion criterion as the source and receiver positions could be different in each situation. In selecting studies for inclusion, papers in which conditions with varying levels of speech intelligibility are compared have to be carefully analyzed.

To provide insight in the inclusion and exclusion of studies that compare different levels of speech intelligibility, three studies are discussed here. Liebl presents the results of a study on the combined effects of acoustic and visual distraction (Liebl et al., 2012). Although all other inclusion criteria are met, the study is excluded based on the method used to achieve the different acoustic situations. In order to create a difference in the speech intelligibility of the signal presented to the subjects, a filter was applied to a speech signal of high intelligibility, based on the insulation properties of a plasterboard wall. The original signal and the filtered signal were then presented at the same sound level during both good and bad speech intelligibility conditions, accompanied by a masking sound originating from the computer's fan control. The reason for exclusion was the fact that the sound in both good and bad speech intelligibility conditions was presented at the same sound level. If, due to screens and absorbing panels the speech intelligibility of a distant source were reduced, this would in reality lead to a reduction of the sound level at the receiver position as well, and therefore an even lower speech intelligibility. While this study provides insight in the effect of degraded speech, the conditions cannot be translated to room acoustic differences.

Another approach was found in a study by Schlittmeier et al. (2008). The effect of background speech varying in intelligibility on three different tasks is investigated in a laboratory setting. A German speech signal was presented at 55 dB(A) in one of the conditions. Two auralized versions of this signal were presented at 35 dB(A), both based on a specific insulation curve of either a double wall with low-pass characteristics or a light wall, representing a mobile wall or screen. Only the comparison between the signal at 55 dB(A) and the 35 dB(A) auralization of a light wall is of interest for this review. The level difference between these two situations is feasible if the distance between source and receiver is more than 10 meters and the study is therefore included. When interpreting the results of this study, however, it has to be taken into account that both signals were presented through headphones in a sound attenuated booth and no other background noise was present. In a realistic situation, the lowered speech signal would have been masked by background noise which is always present and would therefore have been less intelligible.

A third example of a study on the effect of speech intelligibility on task performance is described in Venetjoki et al. (2006). Here, a speech signal mixed with background noise is presented to the subjects. The level of the speech signal in the ‘intelligible’ condition is 48 dB(A), presented at a signal to noise ratio of 13 dB. To create a less intelligible condition, the level of speech is reduced by 8 dB(A) which is feasible when absorption and screens are added to a room. The background level for this condition was however increased by 13 dB(A), representing an active masking system. The study was excluded based on the increased background level.

2.2.3 Search strategy

The search strategy to find relevant studies is based on the reference list of Szalma and Hancock’s review (2011) and two additional literature searches. The search terms that were used in Szalma and Hancock’s meta-analysis, (noise OR speech) AND (memory OR decision-making OR problem-solving OR attention OR vigilance OR tracking OR marksmanship OR shooting OR fine motor OR gross motor), were found to be incomplete for the aim of this study as no terms related to room acoustics were used. Furthermore, the cut-off date for their review was February 2011. Therefore, the search strategy by Szalma and Hancock was repeated for the period of 2011-2016 (cut-off date January 2016), and an additional search was conducted using more search terms related to acoustics and less specific performance indicators. Another difference is the addition of terms relating to the work environment such as ‘employee’ and ‘ergonomics’, which was deemed necessary to reduce the search results to a feasible amount. The search terms included in the additional literature search, based on the PICO strategy (Sayers, 2008), are depicted in Figure 2-1. The search was conducted in Pubmed, ScienceDirect and PsychINFO (using Ovid) to cover a broad area of research. No search terms were used for the comparison (C) part of the PICO strategy, since the decision to include papers is not based on methodological aspects.

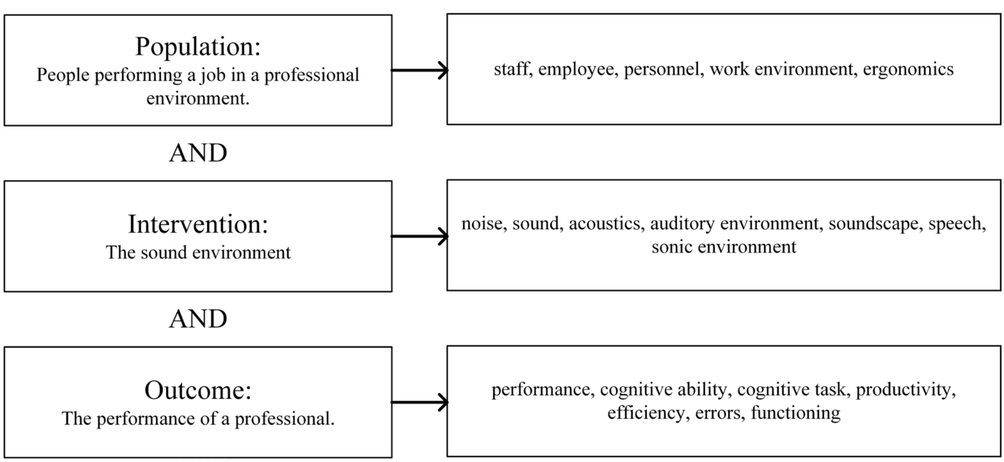


Figure 2-1 Search terms used in the addional literature search

After gathering the results of the two searches, three review rounds were performed to select studies that met the inclusion criteria according to Table 2-1. In the first round article titles were screened, after a removal for duplicates, to exclude all titles that had no relation with the topic. Since the search terms included the word 'sound' which also means 'good' the initial search results contained a substantial amount of unrelated articles. In the second review round abstracts were screened based on the inclusion and exclusion criteria which are shown in Table 2-1. As abstracts do not contain all relevant methodological information, no studies were excluded based on room acoustic theories in this round. The second review round's criteria are similar to the inclusion and exclusion criteria as used by Szalma and Hancock (2011), so that after this round the papers from their review could be added to conduct the third review round. Full text versions of all available papers in the third round were collected to start searching for studies in which the difference between control and experimental situation can theoretically be a result of room acoustic modifications and studies in which the results of a room acoustic intervention are presented. Since the decision whether to include papers in this round is based on the specific experimental conditions of each study, review papers were excluded. For each paper, the following study characteristics were obtained: task/performance measure, type of sound used, and the experimental conditions. The decision to include or exclude the study was based on this information. The review procedure and the number of papers selected in each step is shown in Figure 2-2.

2.2.4 **Method of analysis**

During the selection process, information on the subjects' age, the sound sources which were used, the conditions that were created and the type of task was already collected. Further categorization of the 12 remaining papers after the third review round is based on the outcomes of each study, and the factors that may have influenced or determined these outcomes. Therefore, information on the subjects' other personal factors, the type of room that the study was conducted in or refers to was collected and a translation to room acoustic parameters, if applicable, was made. In the comparison of study outcomes, these methodological aspects of the studies were taken into account.

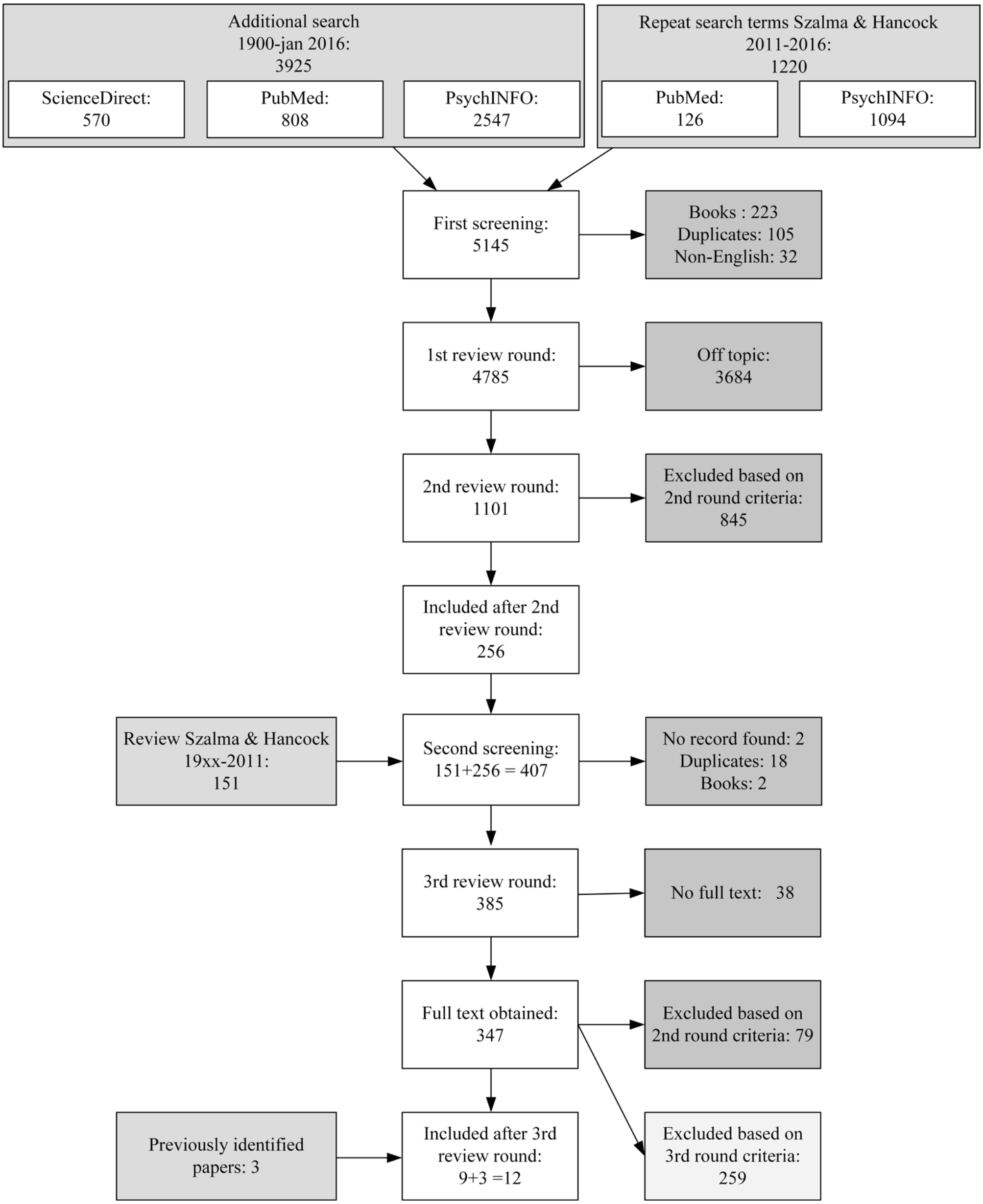


Figure 2-2 Review procedure and overview of selected and excluded number of papers.

2

2.3 Results

The very broad scope of the literature search and corresponding search terms led to a substantial amount of studies in which some variable of the auditory environment was altered in order to measure the effect on human performance. After removing duplicates, books and papers not written in English, 4785 papers were included in the first screening round which was performed by the first author. Based on titles only, 3684 papers were excluded. Papers on the performance of speech-language pathologists, noise induced hearing loss and the development of 'sound' methodologies, designs or practices are well represented within the excluded papers. The abstracts of the remaining 1101 papers were thoroughly read to identify studies fitting the second round inclusion criteria. In the case of any doubt, the paper was included, leaving 256 papers to be studied in the third round together with 129 (without duplicates and books) papers from Zsalma and Hancock's review. Full text versions of 38 papers could not be obtained, these were excluded so that an analysis of the remaining 347 papers could be performed.

Methodological information from all the papers was gathered by the first author based on which the decision was made whether the paper could be used to determine the effect of room acoustics on human performance. During this process, 79 papers were retrospectively excluded based on 2nd round exclusion criteria. Then, based on third round inclusion criteria, the collection was narrowed down to a total of 9 papers which were identified by the described search strategy and 3 more papers which were added as they were previously identified by the author and a colleague. Checking the reference lists of the final set of included papers did not lead to any more inclusions, however, more papers were found that would comply with the criteria of the 2nd screening round. These studies have not been processed in the results.

2.3.1 Results overview

An overview of the methodological aspects and outcomes of the 12 included papers (covering 24 studies in total) is presented in Table 2-2. Source characteristics, room typology, performance measure and personal factors (if reported) are given as well as the study outcomes. Some of the included studies report on multiple sound conditions which do not all comply with the inclusion criteria of this review. The statistical analysis of those studies does not always provide the required information for this review's purpose, those outcomes are marked with an asterisk.

A first observation when looking at Figure 2-2 is the relatively small number of papers that could be included in the third review round as compared to the amount of papers in the second review round. From Table 2-2 it can be read that there are five papers in which actual room acoustic conditions are modified to measure an effect on performance, either by physically changing a room (Haapakangas, Hongisto, Hyönä, Kokko, & Keränen, 2014; Seddigh, Berntson, Jönsson, Danielson, & Westerlund, 2015) or by using auralizations (Balazova, Clausen, Rindel, Poulsen, & Wyon, 2008; Perham, Banbury, & Jones, 2007; Valente, Plevinsky, Franco, Heinrichs-Graham, & Lewis, 2012). The remaining 7 papers were identified from which the theoretical effect of room acoustics on human performance could be deducted. The last column of Table 2-2 provides a short analysis of each study.

Table 2-2 Summary of the papers included after the third review round. The table provides all available information about the subjects' personal factors (age, working memory capacity (WMC), occupation), the number of subjects (N), the type of sound source used in the study, the conditions that subjects were subjected to, the type of room that the study was performed in or should represent, the type of performance which is measured and whether it is a complex task or an ability (explained in the discussion section) and reported outcomes. The last column provides the current author's interpretation of the conditions and results. A * indicates that no statistical analysis is available, as not all study conditions can theoretically be achieved by room acoustic changes.

Ref.	P	N	Source type	Conditions	Room type	Outcome measures	Results	Interpretation
(Balazova et al., 2008)	Mean age = 22	15	Recorded office noise, containing speech.	Office noise trough a 7+1 speaker system in 3 conditions. 1: Auralized recording (ODEON), model includes a sound absorbing suspended ceiling. Average SPL = 52 dB(A). 2: Condition 1 + added sound absorbing baffles and screens. Average SPL= 49 dB(A). 3: Condition 1+ absorbing ceiling replaced with reflective ceiling. Average SPL= 54 dB(A). No information on reverberation times or absorption coefficients.	Participants are seated in a mock-up office, 5 desks in center of room. The conditions represent an open office. More details can be found in Pop & Rindel (2005)	A: Proofreading (complex). B: Text typing (complex). C: Addition (ability). D: Self rated performance (subjective).	A: Performance decrease* in reverberant condition compared to 'real' and absorbent conditions. (falsely detected errors only). B: Speed of text typing shows a clear decrement* in the sound-absorbent office compared to the reverberant and the 'real' office. C: No effects* of sound absorption on addition performance. D: No visible effects* of sound absorption found on self-estimated performance.	Actual acoustic modifications are used to create the different conditions. There is a lack of information with regard to the room acoustic conditions. Reverberation times, decay of sound or speech intelligibility are unclear. The original recordings are not made in an anechoic chamber. The outcomes are task dependent, and suggest that too much sound absorbing materials in an office environment could increase distraction by irrelevant speech for some tasks. Statistical significance cannot be determined.
(Seddigh et al., 2015)	Office employees.	40	Field study, actual office noise.	Three physically built acoustic conditions. 1: Baseline: absorbing ceiling ($\alpha_w = 0.95$) 2: Worse acoustics: 55% of tiles replaced by reflective ceiling tiles ($\alpha_{w=} \sim 0.05$) 3: Better acoustics: absorbing ceiling & wall panels ($\alpha_w = 0.95$)	Open-plan office with an atrium in the middle.	Self- rated professional efficacy. Maslach Burnout Inventory (subscale) (Maslach, Jackson & Leiter, 1997) (subjective).	No significant effect of room acoustic changes on self-rated efficacy was found.	Acoustic modifications are used to create two conditions which represent realistic circumstances. Parameters of interest are the decay of sound and speech intelligibility for various source receiver conditions. A detailed measurement report can be found in (Zalyaletdinov, 2014). No objective outcome measurements were conducted. The results imply that there is no difference in perceived efficacy of office workers between a sound absorbing and a rather reverberant office. The perception of disturbances and cognitive stress, however, were reduced in the sound absorbing condition.

Ref.	(Colle & Welsh, 1976)	
P	Students, age unclear.	Students, age unclear.
N	80	72
Source type	Irrelevant speech in foreign language, single speaker.	
Conditions	Speech binaurally or dichotically presented at 20 dB, 40 dB, and 50 dB. Sound delivered through headphones.	Speech monaurally presented at 70 dB and 76 dB. Sound delivered through headphones.
Room type	Sound attenuated room.	Sound attenuated room.
Outcome measures	Serial recall of visually presented letters (ability).	Serial recall of visually presented letters (ability).
Results	A larger percentage of errors in the 40 dB condition versus the 50 dB condition for the dichotically presented sound (Noise minus quiet performance:~18% vs. ~7%). An opposite and smaller effect (Noise minus quiet performance: ~9% vs. ~12%) for the binaurally presented sound. Both differences are not statistically significant. The performance difference between the 20 dB and 40 dB conditions was statistically significant.	The results indicate a slightly larger percentage of errors in the 76 dB condition (Noise minus quiet performance: ~16% vs ~13%), the effect is not statistically significant.
Interpretation	The 10 dB level difference between conditions 2 and 3 can theoretically be attributed to room acoustics in the case of a single speaker at a distance of several meters from the speaker in a reverberant room compared to a sound absorbing room with sound absorbing screens between source and receiver. In such a case, the level difference of irrelevant (foreign) speech does not lead to a higher short term memory performance. The level of speech is 50 dB or lower, which implies that the speaker is at a distance of several meters from the listener. Adding higher or more screens with sound blocking and absorbing properties between speaker and listener could lead to condition 1, and cause a significant visual short term memory performance increase.	The level difference of a single voice is 6 dB between the two conditions in this experiment, this could theoretically be the case in two similar spaces in which the amount of absorption material in the 'louder' condition is a quarter of the amount in the more quiet condition. The levels used in this experiment (> 70 dB) represent a situation in which the speaker is close to the listener in a 'quiet' room. The listener is in the reverberant field. The results suggest that in a quiet environment with irrelevant speech (foreign) at a close distance doubling the amount of absorption material does not lead to a higher visual short term memory performance.

Ref.	(Valente et al., 2012)	(Haapakangas et al., 2014)
P	Age 19-32, m=25.8.	Age 19-45, m=23.9. Noise sensitivity (NoiSeQ) (Schütte et al., 2007)
N	40	97
Source type	Speech in band-pass filtered noise	Multitalker speech at varying distances from the receiver (2-6 m).
Conditions	Speech signal at 60 dB in noise in 4 conditions: (SNR +10 dB, RT 0.6 s) (SNR +10 dB, RT 1.5s) (SNR +7 dB, RT 0.6 s) (SNR +7 dB, RT 1.5 s) Sound delivered through multiple speakers in the room.	Speech at 53 dB played through 4 speakers at different positions in the room. Two conditions: 1: Sound absorbing ceiling (EN 11654) (ISO, 1997), class A, total area 75 m^2) and walls (class A, 18 m^2), 1.7 m high sound absorbing screens (EN 11654), class B, one-sided area) STInear = 0.8 STIfar = .42. 2: Sound reflecting ceiling and walls, 1.3 m high sound reflecting screens. Total absorption area is 142 m^2 less than in condition 1. STInear = 0.7 STIfar = 0.6.
Room type	Simulated classroom of 18 m^2. Corresponding with presented sound conditions	Open-plan laboratory office in which acoustic conditions were physically realized (8.9 x 9.4 x 2.55 m).
Outcome measures	Comprehension of a classroom learning task in two different presentation modes, discussion and lecture (complex).	A: Serial recall of visually presented digits (ability). B: n-back task (ability) C: Operation span (ability). D: Text memory task (complex).
Results	Interaction effects were found for condition (lecture or discussion) and SNR, and for condition and RT. Comprehension scores were more affected by SNR and RT in the discussion condition than the lecture condition. Adverse acoustics (SNR +7 dB, RT 1.5 s) led to lower comprehension scores. The results indicate a stronger effect of SNR than of RT.	A: Worse performance in condition 1 during serial recall task, largest difference in noise sensitive group. Statistical significance unclear*. B: Condition 1 shows shorter reaction times during n-back task. Statistically insignificant. No effect of noise sensitivity. C: No statistical significant effect of noise condition or noise sensitivity. D: No statistical significant effects of the conditions on text memory performance. No interaction effect for working memory capacity and acoustic condition.
Interpretation	Actual acoustic modifications (modeled) are used to create the different conditions, a theoretical translation to room acoustics is therefore not applicable. The task and the simulated environment have a high ecological validity and can be translated to classroom settings.	Actual acoustic modifications are used to create the different conditions, a theoretical translation to room acoustics is therefore not needed. The results suggest that in an open office environment with multiple speech sources at various distances the effects of room acoustic changes on the performance of an n-back task, operation span and text memory are nonexistent. The effect on visual short term memory, task A, is undetermined. In their paper, the authors discuss several factors that could explain the statistical insignificance of the measured effects. These include both methodological limitations and the practical limitations of room acoustic design.

Ref.	(Schlittmeier et al., 2008)			(Rönnberg, Rudner, Lunner, & Stenfelt, 2014)
P	Age 20-37.	Age 19-38.	Age 19-27.	Age 22-45, m=31.6. Working memory capacity
N	28	24	20	39
Source type	Speech: semantically meaningful sentences.			Speech in stationary speech shaped noise (SSN)
Conditions	1. Speech signal of high intelligibility at 55 dB(A). 2. The same speech signal auralized based on the insulation properties of a lightweight screen or partition (35 dB(A)). Sound delivered through headphones.			Signal in SSN, 3 conditions. 1: SNR -2 dB 2: SNR -4 dB 3: SNR -6 dB Sound delivered through headphones.
Room type	Double walled sound proof booth.			'Quiet office'.
Outcome measures	Verbal- Logical reasoning (complex).	Mental arithmetics (ability).	Serial recall of visually presented items (ability).	Auditory and memory processing. The task requires hearing, remembering and processing of semantic content (complex). The task comprises 3 memory load levels
Results	1: 27% error rate 2: 27% error rate No significant difference.	1: 36% error rate 2: 34% error rate No significant difference.	1: 41% error rate 2: 39% error rate No significant difference.	Memory performance decreased with worse SNR for subjects with high working memory capacity only. No main effect of SNR was found.
Interpretation	The difference between the two conditions of interest can theoretically be achieved in a large office with a single speaker at a distance of at least 10 meters. Sound absorbing and insulating screens should be placed between source and receiver to create condition 2. The results imply that such an intervention does not cause a significant effect in visual short term memory, attention (concentration) and the more complex task of verbal-logical reasoning. The lack of background noise in both conditions could be a reason for not finding differences. In all three tests, condition 2 was rated as less disturbing than condition 1.			The difference in SNR is created by adding background noise. This can theoretically correspond to a situation in which a listener is within the direct sound field of a speaker while the overall level of background noise lowers as a result of more sound absorbing material. The results can be translated to lecture or presentation settings, lower background noise can lead to better auditory and memory processing of listeners with a high WMC.

Ref.	(Ljung, Israelsson, & Hygge, 2013)	(Surprenant, 1999)
P	Age 19-35, Working memory capacity, high and low.	Students, age unclear.
N	35	60
Source type	Speech in white background noise	Speech and white noise
Conditions	Speech signal in 4 different conditions, sound level unknown. 1: (SNR + 12 dB, STI = 0.73). 2: (SNR + 9 dB, STI = 0.64). 3: (SNR + 6 dB, STI = 0.55). 4: (SNR + 3 dB, STI = 0,46). Sound delivered through headphones.	Speech signal at 65 dB in white noise in two conditions. 1: SNR +10 dB 2: SNR +5 dB Noise conditions were either mixed and presented randomly or blocked and predictable. Presentation mode undefined
Room type	Sound isolated test room.	Undefined.
Outcome measures	Free recall of aurally presented words (ability).	Serial recall of aurally presented syllables (ability).
Results	A significant effect of SNR on memory performance was found for subjects with low WMC. Largest decrement between conditions (SNR + 12 dB, STI 0.73) and (SNR + 9 dB, STI 0.64). No effect of SNR on memory performance found for subjects with high WMC. No effect of WMC on speech intelligibility for the different SNR conditions.	Results are presented as a function of serial position, separate results are presented for subjects who received random noise conditions and for subjects receiving predictable noise conditions. Significant reduction of short term memory performance for condition 2 in the random presentation mode, largest effect is seen in the most difficult serial positions. In the case of predictable presentation mode, a reduced performance in seen only for the final two serial positions in condition 2.
Interpretation	The difference in speech intelligibility is created by adding background noise. This can theoretically correspond to a situation in which a listener is within the direct sound field of a speaker while the overall level of background noise varies as a result of more sound absorbing material. The results can be translated to lecture or presentation settings.	The difference in SNR is created by adding background noise. This can theoretically correspond to a situation in which a listener is within the direct sound field of a speaker while the overall level of background noise varies as a result of more sound absorbing material. In the case of a 5 dB difference, this would mean that the amount of absorption material in condition 1 would be almost double the amount in condition 2. The results can be translated to lecture or presentation setting, lower background noise can lead to a better auditory short term memory performance.

Ref.	(Murphy, Craik, Li, & Schneider, 2000)	(Wilding, Mohindra, & Breen□Lewis, 1982)
P	Age 20-24.	Students, age unclear.
N	26	80
Source type	Speech in multitalker babble	White noise
Conditions	Signal in multitalker babble, two conditions: 1: SNR -5 dB 2: SNR -10 dB Sound delivered through headphones.	White noise in two conditions: 1: 65 dB(C) 2: 75 dB(C) Sound delivered through headphones.
Room type	Single-walled sound attenuated chamber.	Undefined.
Outcome measures	Serial recall of words, aurally presented (ability).	Free recall of visually presented words: A: Associated ,semantic orienting (ability). B: Non-associated, semantic orienting (ability). C: Associated (ability). D: Non-associated (ability).
Results	Performance in the first three serial positions is best in the low noise (SNR -5 dB) condition, whereas noise level had no influence on performance in the last two serial positions and the first serial position.	No significant main effect of noise emerged. In the orienting tasks (A&B), subjects performed better in 75 dB(C), condition 2, for both associated and non-associated lists. Subjects performed better under condition 1 in the non-orienting tasks (C&D). The experiment also included a 85 dB(C) exposure condition. For the non-associated lists, this condition improved performance compared to the lower noise exposures in the non-orienting task and reduced performance in the orienting task.
Interpretation	The difference in speech intelligibility is created by adding background noise. This can theoretically correspond to a listener within the direct sound field of a speaker while the overall level of background noise varies as a result of more sound absorbing material. The more difficult task is in this case more (negatively) influenced by noise. The results can be translated to lecture or presentation settings.	White noise is used, with a difference between conditions of 10 dB. This can only be an effect of room acoustics in a multitalker situation (babble). Quadrupling the amount of absorption area in a space with multiple speakers in the reverberant field could theoretically cause the difference between condition 1 and 2. The results can be translated to a large office setting with multiple speakers, e.g. a call center. The effect of lower background noise is dependent on the task content even if the same ability (visual short term memory) is measured.

2.4 **Discussion of results**

In the previous section, the experimental conditions and outcomes of each study were translated to the effect of a possible room acoustic intervention on task performance. To analyze the data in Table 2-2, a distinction is made based on the role and type of sound in each experiment, which can be either a distractor (Balazova et al., 2008; Colle & Welsh, 1976; Haapakangas et al., 2014; Perham et al., 2007; Schlittmeier et al., 2008; Seddigh et al., 2015; Wilding et al., 1982), or part of the task (Ljung et al., 2013; Murphy et al., 2000; Rönnberg et al., 2014; Surprenant, 1999; Valente et al., 2012). Three types of sound were used in the studies considering sound as a distractor:

- speech (Colle, 1980; Haapakangas et al., 2014; Schlittmeier et al., 2008);
- broadband noise (Wilding et al., 1982);
- and typical office sounds (Balazova et al., 2008; Perham et al., 2007; Seddigh et al., 2015) (e.g. typing, printing, speech, walking sounds).

Speech and a masking sound are used in Ljung et al. (2013), Murphy et al. (2000), Surprenant et al. (1999), and Valente et al (2012). Here, speech is part of the task, and a higher speech intelligibility is assumed to improve task performance. The outcomes suggest that for situations in which communication through speech such as lectures, presentations and meetings is a regular activity, performance of hearing, processing and remembering the speech content is affected by the signal-to-noise ratio of the presented speech. In these situations a slightly higher signal-to-noise ratio, which can theoretically be achieved for short speaker-to-listener distances through adding sound absorbing material to a room, has a positive effect on serial recall performance (Murphy et al., 2000; Surprenant, 1999), free recall (Ljung et al., 2013), auditory processing and memory (Rönnberg et al., 2014) and comprehension of a classroom learning task (Valente et al., 2012). The experimental conditions of the studies cannot easily be compared. Both positive and negative SNR's were used and the differences between conditions within each study vary as well as the masking sounds that were used. Overall though, the results of these studies are consistent, a higher speech intelligibility improves performance, dependent on the working memory capacity of the subjects (Ljung et al., 2013; Rönnberg et al., 2014), and task difficulty (Murphy et al., 2000; Surprenant, 1999).

In three studies speech is considered a distractor of which the level of intelligibility, determined by actual room acoustic properties (Haapakangas et al., 2014), the sound level at which the speech is presented (Colle, 1980), or both (Schlittmeier et al., 2008) are used as the independent variable. Again, comparing the outcomes is hard, as the actual speech signals which were used in the experiments (speech in a foreign language, multitalker speech and semantically meaningful sentences) are very different. Lowering the level of speech in a foreign language from 40 dB to 20 dB, which could theoretically be realized by increasing the amount of sound absorption in a ceiling and adding sound absorbing and blocking partitions, improves serial recall performance, while a smaller difference does not show this effect (Colle, 1980). In the multitalker situation, however, a physically built sound absorbing ceiling and absorbing screens seem to reduce serial recall performance (statistical significance not determined due to other experimental conditions). The use of different sound sources could be one of the reasons for these contradicting results. Based on the included studies, the effect of room acoustics on human performance is unclear when speech is seen as a distractor. Given the many studies on the irrelevant speech effect (Elliott & Briganti, 2012; Neely & LeCompte, 1999; Park, M., Kohlrausch, & van Leest, 2013), this is an unexpected finding. Furthermore, the results imply that the effect of room acoustics on human performance is dependent on the task and on personal factors (Haapakangas et al., 2014).

One study is included which reports the effects of the level of white noise on serial recall performance (Wilding et al., 1982), in this case the difference between conditions can only be attributed to acoustics (combined with the Lombard effect) if the white noise is seen as multitalker speech. No significant effect of noise level was found, but interaction effects indicate that the effect of noise is task dependent.

The third sound type, office noise, is used in three of the included studies (Balazova et al., 2008; Perham et al., 2007; Seddigh et al., 2015). Only one of the three studies using office noise reports an effect on performance (Balazova et al., 2008), but as other conditions were included in the experiment, we could not determine the statistical significance. Again, the outcomes are task dependent, proofreading performance (finding errors in a text) was worse in the reverberant condition compared to the other two conditions, while the speed of text typing was slower in the absorbent condition. A reason for not finding significant differences in (Perham et al., 2007) could be the relatively small difference (reverberation time of 0.7 s vs 0.9 s) between conditions. In Seddigh et al. (2015), no effect of the room acoustic modifications was found for a subjective measure of performance, while subjects did report lower perceived disturbances and stress. People might underestimate the effect of the sound environment on their own performance, as seen in (Weinstein, 1974) where subjects performed significantly worse on an objective proofreading task in noise in contrast to their own belief.

Based on the eligible papers for this study, it seems that the effect of room acoustics on human performance is dependent on the sound source and its relation to the job or task, on the task itself and on the personal factors of the person performing the task. We argue that knowledge on job characteristics, the sound sources including their relation to the (expected) task at a workplace and, if possible, personal factors of employees is a prerequisite to create a good room acoustic design. This can be visualized in a conceptual model on the effect of room acoustics on human performance.

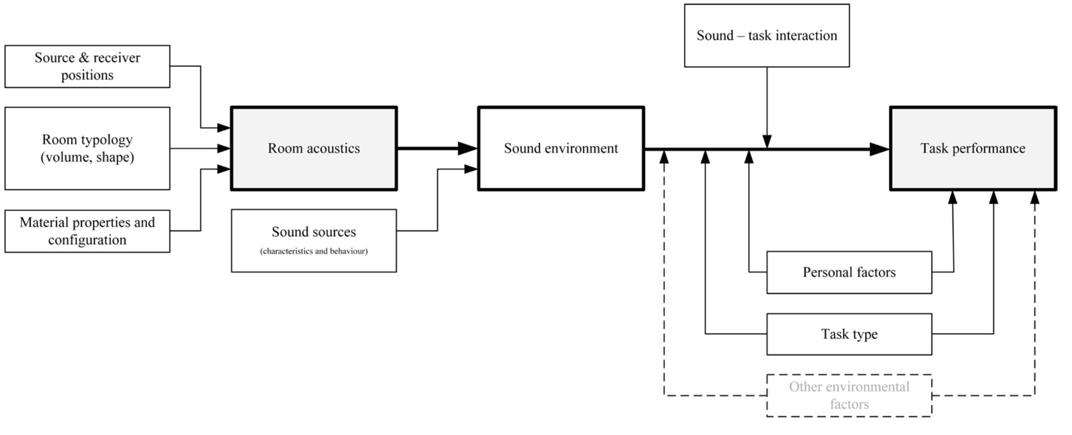


Figure 2-3 Conceptual model on the influence of the sound environment on task performance.

2.4.1 **Conceptual model**

Our conceptual model, depicted in Figure 2-3, is based on the obvious but important separation between room acoustics and the sound environment. It is the sound environment that influences task performance, not room acoustics. Room acoustics, though, do influence the sound environment. The model is furthermore based on general room acoustic principles, and the results of the papers eligible for this review. The results of studies which were included in the second review round but excluded in the third review round are used to explain and strengthen the model.

The indoor sound environment is, considering a well-insulated area, determined by both the sound sources and the room acoustic properties of the space. There is no sound environment, and therefore no effect of room acoustics without a sound source. Multiple studies on the effect of sound on human performance show that this effect is dependent on the type of source and its behavior. In reviews by Suter (1989) and Szalma and Hancock (2011) it is concluded that intermittent sound has a more disruptive effect on performance than continuous sound, and unfamiliar or unexpected sounds show an even larger performance decrement. Another example can be found in Marsh et al. (2009) who show that meaningful speech has a more disruptive effect than meaningless (e.g. foreign language) speech on a semantic task.

Room acoustic parameters are the result of a room's shape, volume and materialization. The sound environment is characterized by the combination of room acoustic parameters which means, for example, that the resulting sound environment in rooms with equally long reverberation times and the same sound source could still be very different. Furthermore, room acoustic parameters are dependent on the location of both the sound source(s) and the receiver in a room. For each combination of space typology (narrow corridor vs open plan space), source type, behavior and location, the effect of sound absorbing materials on the auditory environment can be determined. The effect of room acoustics on the sound environment can only be generalized towards those situations which are similar in these aspects.

The results of this review suggest that task type influences the effect of the sound environment on task performance (Balazova et al., 2008; Haapakangas et al., 2014; Murphy et al., 2000; Surprenant, 1999; Valente et al., 2012; Wilding et al., 1982), which is in line with Szalma and Hancock (2011). A closer look at the term 'task performance' reveals that performance in itself is task dependent, the type of task (and its complexity) therefore also has a direct influence on task performance. Personal factors were also revealed as aspects that influence the effect of sound on human performance. Other than noise sensitivity (Schutte, Marks, Wenning, & Griefahn, 2007) and working memory capacity (Ljung et al., 2013; Rönnberg et al., 2014), there are several more personal factors of which the moderating role on the effect of sound on people's performance has been established. Examples can be found for emotional state such as sadness (Pacheco-Unguetti & Parmentier, 2014) and introversion (Belojevic, Slepcevic, & Jakovljevic, 2001). Furthermore, as people age, their hearing ability deteriorates, especially for higher frequencies (Gates & Mills, 2005). This affects, amongst others, speech intelligibility, the ability to discriminate speech against a background and the ability to detect the direction from which sounds are originating (Gates & Mills, 2005). Similar to task type, personal factors can both influence task performance directly, and influence the effect of the sound environment on task performance.

An obvious difference in the outcomes of included studies was observed based on the role of the sound environment for a task, the sound-task interaction is therefore included in the model. Finally, as research has shown that the integration of information from different sensory systems is a fundamental characteristic of perception and cognition (Ghazanfar & Schroeder, 2006), other environmental factors are included in order to offer an integrated approach for room acoustic design.

2.4.2 **Implications based on the model**

The conceptual model in Figure 2-3 illustrates the complexity in defining the role of room acoustics in the effect of sound on human performance. Each aspect included in the model has been shown to influence the outcomes. They are, therefore, important factors to take into account in the interpretation of studies or the design of an experiment aimed to gain knowledge on the role of room acoustics on human performance in a natural work setting. In the sections below, recommendations for future research are presented based on each aspect of the model.

2.4.2.1 ***Sound sources***

The sound sources in a workplace are in most cases largely determined by the type of job that is performed there and the user habits (it is obvious that the main source of sound in a call-centre, human speech, is very different from that in a small chemical laboratory with a few people doing very concentrated and individual work).Yet only the combination of sound sources that is typical for an office environment was used as an experimental sound in the included studies. It was seen that it belongs to the most used sources (along with speech and broadband) in the excluded studies as well. A recommendation based on the different source types and behavior that are used in the included studies is to conduct analyses of the sound environment in a broader variety of typical workplaces. Reliable data on the actual sound environment can serve as input for laboratory experiments (Liebl, Wenzke, Troll, & Kittel, 2014).

In the included studies, sound is considered to be either a distractor, or an essential part of the task. This clear distinction may not always be present in natural work settings. Furthermore, people who are instructed that all sound can be ignored, or informed that sound has a negative influence on performance tend to react differently to sound than people with opposite instructions (Iacono & Lykken, 1983). In two of the included papers in which sound is not part of the task itself, participants are explicitly told that any sound is task-irrelevant and can be ignored (Haapakangas et al., 2014; Schlittmeier et al., 2008). Similar instructions are found in studies excluded in the third review round (Banbury & Berry, 1998; Elliott & Briganti, 2012; Halin, Marsh, Hellman, Hellstrom, & Sorqvist, 2014). This cannot be compared to a realistic work environment in which speech from colleagues may also be directed at you. In some specific settings, shielding yourself from any external stimuli might even be detrimental to work performance. An obvious example can be found in nursing, in which it is important for patient safety to be constantly aware of the environment, but also for a teacher, a factory employee, a restaurant waiter and for an office employee it is not always possible to ignore the auditory environment. An important consideration for future studies is to investigate and include the role of the sound environment for the specific task or job.

2.4.2.2 ***Space typologies***

The space typologies that are represented by the included studies are two open-plan offices (size unknown), an 18 m^2 classroom, a medium sized, almost square office of around 80 m^2 and sound attenuated laboratory booths. As the effect of room acoustic design on the sound environment becomes more pronounced with increasing distance between source and receiver (Haapakangas et al., 2014), its effect on human performance in environments with larger distances between distracting sources or different shapes, such as long corridors can be expected to be more pronounced as well. The limited amount of evidence on a broader variety of space typologies and their use could be addressed in future research.

2.4.2.3 ***Task types***

To assess the effect of sound on task performance the ability requirements approach has been introduced as a potentially useful taxonomy by Fleishman (1975). This approach centers around the idea that certain abilities are required for maximum performance of certain tasks. Some examples of abilities are memorization, mathematical reasoning, information ordering, control precision and reaction time. Tasks that require similar abilities can be placed in the same category or can be regarded as similar. The effect of room acoustics on a task could then be expected to be seen similarly on other tasks requiring similar abilities. In 16 out of 24 included experiments the effect of acoustics on a task designed to measure an ability are presented (Balazova et al., 2008; Colle, 1980; Haapakangas et al., 2014; Ljung et al., 2013; Murphy et al., 2000; Perham et al., 2007; Schlittmeier et al., 2008; Surprenant, 1999; Wilding et al., 1982). Recall of visually or aurally presented items, for example, is a commonly used performance measure to assess memorization. While the importance of memorization or other abilities in various job settings should not be underestimated, the effect of room acoustics on an ability cannot be generalized to complex task performance, let alone to job performance. The results of these experiments are useful in acoustic design if an analysis of the required abilities for the job that is to be performed is available. Proofreading (Balazova et al., 2008), text memory (auditory and visually) (Haapakangas et al., 2014; Rönnberg et al., 2014), text typing (Balazova et al., 2008) and comprehension of a classroom learning task (Valente et al., 2012) are the complex tasks for which an effect of room acoustics, given a certain sound environment, is reported in this review. These experiments are closer related to a task in the natural working environment.

The included studies, with exception of (Seddigh et al., 2015), focus on a task or ability and not on the characterization of a job that is performed in a specific area. While measuring abilities and complex tasks might tell us something about a small part of the job, operationalizing the full process of complex tasks is a necessary next step (Sörqvist, 2015). For future studies aiming to establish the effect of room acoustics in a certain environment, this means to not exclusively look at the performance of each task, but to take into account the planning, prioritizing and executing (or not) of the consecutive tasks as well. Furthermore, job performance, defined as the overall expected value from employees' behaviors carried out over the course of a set period of time (Motowildo, Borman, & Schmit, 1997), comprises both task performance and contextual performance. Contextual performance refers to a behavioral aspect which cannot be measured in laboratory experiments aimed at direct results. Examples of behavior that fit under the umbrella of contextual performance are helping out a colleague or creating a positive social atmosphere in a department. Subjective evaluations of performance such as conducted by Seddigh et al (2015), or studies on psychosocial aspects, such as performed by Blomkvist et al. (2005), could provide more insight on contextual performance. The scope of the current work did not include the psycho-social aspects of the working environment as a performance indicator, however.

2.4.2.4 ***Personal factors***

From the results in Table 2-2 it can be read that most studies are conducted with young adults or students, the age range is 19-45. The included field study (Seddigh et al., 2015) does not report the age of the subjects, but given the fact that the study is conducted in an office environment it is expected that a mixture of the working population age is represented. Addressing older age groups in future studies seems a logical step considering the ageing workforce (Crawford, 2016), and the fact that age has an effect on our hearing ability. Working memory capacity (WMC) (Ljung et al., 2013; Rönnberg et al., 2014) and noise sensitivity (Haapakangas et al., 2014) are the only personal factors moderating the effect of room acoustics on human performance identified in this review. Although every individual will differ in its way of reacting to the environment, workplaces are generally built to be suitable for a group of workers. To determine the effect of room acoustics on job performance for a group of people performing the same job in the same sound environment, establishing personality traits by means of questionnaires or other available data available on the personalities of a certain population can improve future studies. Literature on the moderating effect of personal factors, such as (Oseland, 2009) can be used to determine which factors to control for. In the design of experiments, subjects should be selected that represent the population under study.

2.4.2.5 *Other environmental aspects*

It can be seen from both the included and the excluded material that there are very few studies in which the auditory conditions are congruent with the other sensory conditions. In these cases, recorded sound is presented through speakers or headphones in a sound attenuated booth or a laboratory. In natural working conditions the auditory environment is a result of activities in a room. Working on a task in an isolated booth while hearing typical office sounds could be considered unnatural (Annerstedt et al., 2013; Viollon, Lavandier, & Drake, 2002). Whether the visibility of sound sources is of importance for the amount of performance decrement could be investigated in future studies.

2.4.3 **Inclusions after the second review round**

The results of the second review round show that there are over 250 studies showing the effect of sound and noise on human performance. Studies in which moderate level differences of 10-30 dB have been used indicate that combining acoustical interventions with other noise reduction strategies may lead to positive outcomes. Despite the fact that from these studies the role of room acoustics is unclear, they are useful for determining in which situations the role of acoustics can be expected to be significant. The 259 references that fully complied with the 2nd round inclusion criteria and of which full text copies could be obtained might be of value for other research purposes and they are therefore included in appendix A.

2.5 Study limitations

The search terms included terms relating to the work environment to limit the number of papers which possibly increased the risk of missed papers. The inclusion of papers which were not identified through the search strategy confirms this risk.

2.6 Conclusion

The main objective of this review is to answer the question to what extent the current knowledge on the effects of sound on human performance can be used to identify the role of room acoustics. Only a small proportion of the available studies measuring the effect of sound on human performance can be used, and the generalizability of these studies is limited to settings in which source type, sound-task interaction, room type, task type and personal factors are similar to the experimental settings. To show how these aspects relate to the effect of room acoustics on human performance a conceptual model is suggested. The distinction between the effect of sound on human performance and the effect of room acoustics on the sound environment is an important aspect of the model, ignoring it could lead to overestimating the role of room acoustics. Furthermore, translating the outcomes of studies measuring the effect of sound on human performance to the role of room acoustics directly, without taking all the factors in the conceptual model into account could lead to wrong assumptions.

Room acoustic design can be a strategy to control the sound environment in a workplace. However, evidence regarding the effectiveness of this strategy with respect to human task performance is lacking and should be a focus area in future studies. The present review presents those combinations of source characteristics, room typology, job or task characteristics and personal factors for which an effect of room acoustics on performance has been established. It can be concluded that little knowledge is available. Even more so, it shows the complexity of measuring the effect of room acoustics on job performance for the various types of workplaces and the typical jobs that are performed.

3

Gaining insight in the sound environment, the task and their interaction at a workplace: A field study in a nursing ward

3 Gaining insight in the sound environment, the task and their interaction at a workplace: A field study in a nursing ward

In order to measure the effect of the sound environment on job performance in a realistic setting, a thorough understanding of the specific workplace is required. A novel approach, combining audio recordings with qualitative methods as job observation, the Think Aloud method, and questionnaires, was used to gain insight in the sound environment, the task and their interaction in a nursing ward. The current chapter focusses on the development of this approach and ends with an overview of results. For the chosen setting, the approach showed to be valuable in terms of gathering data regarding the cognitive tasks of a nurse (prospective memory, PM), the sound environment at a ward, and the interaction (relevant/irrelevant distractions) between sound environment and PM task. This field study formed an essential starting point to gain insight in the effect of environmental factors such as sound on human performance in an applied setting.

This chapter is based on:

Reinten, J., Hornikx, M. C. J., Kohlrausch, A. G., & Kort, H. S. M. (2016). Auditory distraction and hospital nurses' cognitive performance: an observational case and literature study. In *Book of proceedings: 6th International Ergonomics conference* (287-294). Croatian Ergonomics Society.

Reinten, J., Kort, H. S. M., Hornikx, M. C. J., & Kohlrausch, A. G. (2017). Context specific analysis of the sound environment at the workplace and its relation with a task. In *12th ICBEN Congress on Noise as a Public Health Problem, 18-22 June, Zurich, Switzerland* [3862] Zurich.

3.1 **Introduction**

In recent years, a main focus in the acoustic design of working environments tends to be on the elimination of distraction and improvement of privacy, especially in open-plan offices (Cabrera, Yadav, & Protheroe, 2018; Kim, J. & De Dear, 2013; Yadav et al., 2018). While field studies and surveys clearly show that comfort and satisfaction in a workplace are affected by the sound environment, the (objectively measured) effect on human performance has not yet been fully understood. Objectively measuring the effect of sound on human performance is generally done in laboratories. Based on an extensive review of such experiments, it was concluded that it is difficult to translate most findings to realistic situations (**Chapter 2**). In line with Beaman (2005), three challenges were identified that, if not sufficiently dealt with, hamper the adequate translation of laboratory results to design choices regarding the sound environment at a workplace.

The first challenge is the complexity of the sound environment itself. Architectural design, room acoustic design, building services design, interior design, organizational management, facility management and even the purchasing department are determinators of the sound environment of a workplace. Their influence on the actual sound environment can be predicted to some extent, and for each discipline it is both interesting and relevant to study how they can contribute to a sound environment that does not impair but may rather support or improve human performance. In doing so, experimental conditions should be a realistic representation of the sound environment at a workplace, as should be the changes in the independent variables such as sound levels.

The second challenge can be found in the tasks that are performed in actual workplaces and whether they can be captured in an experiment. In cognitive psychology, sound is often used to study the human brain's reaction to external stimuli as a means to understand how information is processed. The goal in such experiments is not necessarily to find the optimal circumstances to perform a job, which may explain why, often, experimental tasks are chosen that measure an ability rather than a complex task. In order to translate the findings of such experiments, an analysis of the tasks that are performed at a specific workplace, and the abilities that are required for such a task is necessary (Sörqvist, 2015).

The third challenge is what we describe as 'sound-task interaction. The possible meaning of the sound environment for a task should not be underestimated. For example, in most experimental settings, subjects are specifically instructed to focus on the task at hand and to ignore background sound. This mindset allows for a pure analysis of the effect of (for example) irrelevant background sound on task performance. In such situations, subjects have the foreknowledge that sounds can be regarded as task-irrelevant. In contrast, in many realistic work environments, situational awareness including openness to sound events is an important prerequisite for adequate job execution. It can be the source of feedback or required information, and ignoring a sound may in many cases be detrimental for job performance (Kaber & Endsley, 1997; Stanton, Chambers, & Piggott, 2001). The 'task-sound' interaction is unique for a job and the sound environment in which it is performed and should, therefore, be taken into account in the design of an experiment.

The current chapter describes an experimental approach to overcome the three challenges described above, for a specific work environment. A field study was conducted in a nursing ward, with the goal of characterizing the complex tasks that are performed, the sound environment they are performed in and the role of the sound environment for these tasks (task-sound interaction). Finding causal relations between the sound environment and job performance was not the goal of this study, whereas gaining insight in the complexity of the situation was. Therefore, the current chapter focusses on the methodology of this field study to characterize an example approach also usable in other settings. The analysis and discussion of results are presented in **Chapters 4 and 5** of this thesis.

As mentioned, our focus is on nurses working in a hospital ward. This is a large target group, as approximately 10 percent of the active EU workforce is engaged in the health sector in its widest sense (Sermeus & Bruyneel, 2010) of which, together with midwives, nurses make up the largest proportion (Büscher, Sivertsen, & White, 2010). Hospital nurses are responsible for the recovery and well-being of patients; their efficiency, productivity and task performance can be directly linked to patient safety and satisfaction which are important drivers for hospitals (Devers, Pham, & Liu, 2004; John, 1992).

3.2 Defining the scope

Addressing the three challenges as mentioned in the introduction regarding sound environment, performed tasks and task-sound interaction in one study scenario leads to a very broad scope. While audio recordings can provide a complete picture of the sound environment at a workplace, defining more specific study parameters regarding task performance and the sound-task interaction was considered essential for effective data collection. Therefore, the scope was narrowed for both task performance and task-sound interaction, based on an initial observation of the work environment under study. Two themes emerged from this initial observation which, complemented by literature led to the focus of our exploration.

3.2.1 Method of the initial observation

A three-day observation study and a follow-up literature study have been performed by the author in a Dutch top clinical hospital. This initial observation was conducted open-minded without focusing on predetermined aspects of the environment or specific activities of the nurses, which shows resemblance to a grounded theory approach (Stern, 1980). A qualitative analysis of the observation data was compared to findings from literature to construct a first hypothesis on the role of the auditory environment in nursing performance. Another reason for conducting these initial observations was to get acquainted with the context of the work environment under study.

The observations were conducted to gather data on nursing activities and the physical environment in the ward. Throughout a day-, evening-, and night shift a nurse was shadowed (a different nurse each shift) at a combined urological and cardiovascular ward. The ward was chosen based on the willingness and availability of the ward manager to cooperate. A day shift in this hospital ward lasted from 7.00 or 7.30 AM until 4.00 PM, the evening shift from 3.30 PM until 11.00 PM and the night shift from 10.30 PM until 7.30 AM.

The shadowed nurses' activities, behavior (hurrying, whispering, speaking loudly etc.) their verbal, task-related comments or comments about the environment were logged as well as the nurses' interaction with the environment (closing a curtain, switching off a light). Additionally, the author's perception of environmental aspects such as odours, lighting levels and sound events were written down. No further objective measurements of environmental aspects were conducted. The author's interpretations based on observed behavior were also recorded, an example is a comment on the shadowed nurse coming across stressed. The logs were used to create a rough timeline of the three shifts. The interval between log entries varies with the number of activities of the nurse and the events perceived by the observer.

The staff members working at the ward during the shift were informed of the researcher's presence by their manager. They were told that the indoor environment and their tasks were being studied. Three experienced female nurses were assigned by the ward manager and voluntarily cooperated with the study. The nurses were asked to perform their job as usual and answer questions asked by the researcher.

Figure 3-1 presents a schematic layout of the ward, it consists of two corridors, crossing each other in the middle. Only single patient rooms, 22 in total, are present in this ward. A closed nurses' station with a desk in front (marked with 'N' in Figure 3-1) is visible from almost every position in the corridors. The visitor's entrance is separated from the service entrance to part the different traffic flows. A small coffee corner and seating area are situated in a wider part of the corridor, near the visitor's entrance. Besides patient rooms and the nurses' station, there is a large meeting room, a doctors' office, a medication room, a rinsing room, and a storage room. The walls in all spaces are either plastered, covered with wallpaper or made of glass. The floor has a hard-coated finishing. The ceilings in the corridor, nurses' station, medication room and rinsing room are suspended; a mix of glass wool panels and perforated gypsum. The walls and ceilings in the patient rooms do not have any substantial acoustic sound absorption material. Additional panels of mineral wool were installed on the walls of the nurses' station and the meeting room.

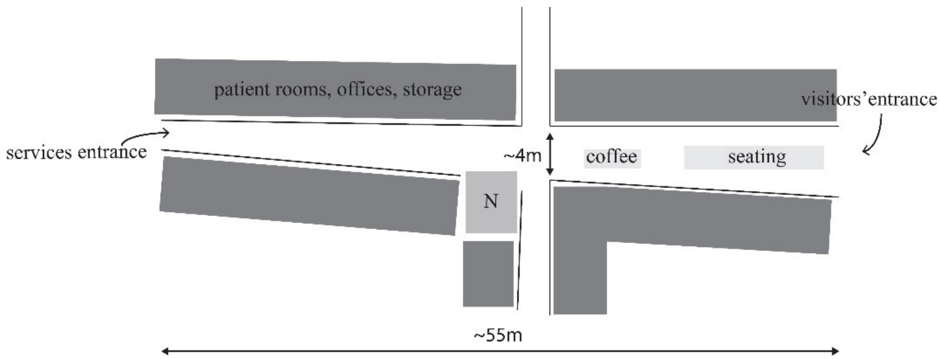


Figure 3-1 Schematic layout of the ward.

3.2.2 **Results of the initial observation**

Both the nursing activities and the auditory environment during the night shift were found to be very different from the day- and evening situation. Compared to the day- and evening shifts, the night shift contained less activity. Patients were generally sleeping and a large part of the shift was filled with administrative work and medication preparation. Only two nurses were present at the ward, and no doctors or visitors. The ward was perceived by the author as quiet. The night shift was therefore excluded from further study. First a general overview of the shift is presented followed by a description of themes that emerged from the data.

During the day- and evening shift, three experienced nurses were responsible for the ward, and there were one or two nursing students at work. Meals were served by the service staff, they take care of towels and bedlinen as well. Each nurse was responsible for roughly one wing of the ward (7 or 8 rooms), and cared for his or her own patients during the shift. Most of the tasks were generally handled alone. There was no strict time schedule for tasks to be done, but there was a general order in which the nursing tasks are usually performed. The day shift started with the change-of-shift report followed by activities to get the patients ready for the day, such as washing up and changing clothes. This is also referred to as activities of daily living (ADL). Then, depending on the doctors' schedules, the nurse accompanied a doctor during visiting rounds or started with medication rounds. They generally try to finish the medication rounds, ADL care and all necessary measurements before noon. Discharges, installing new patients or transports to the operation room (OR) can occur throughout the day and filled most of the afternoon. Fixed tasks of the evening shift were a medication round, checking the patients' vitals and getting them ready for the night. Furthermore, similar to the day shift, discharges, new patients and OR trips were occurring. Entering patient data in the electronic medical records (EMR) should be performed during the shift, but generally, time does not allow for this.

Figure 3-2 shows a segment of the timeline constructed from the observations. Logs about environmental aspects other than sounds, the nurses' interactions with the environment unrelated to sound (such as increasing the intensity of a light) and general comments about the nursing process are not shown here. The timeline indicates that sequential tasking and interruptions are very typical for the nursing job. It shows that while preparing the discharge of patient Y, she is called by patient X. After attending to patient X, she does not immediately return to her original task (the discharge) but starts a new task for patient X. This is supported by a comment from the nurse made at the end of the day shift saying there are always many things of which she thinks "oh right.. this has to be done as well right now".

Even though there is no strict time schedule, the behavior of the nurses led to our interpretation that delays in discharge, new patients and visits to the OR can lead to some stress concerning time management. Specific comments of the nurses strengthen this assumption, an example can be seen in a fragment of the timeline logs in Figure 3-2, "relatives of patient Y are not here yet, this messes up the schedule of nurse 1".

The following description of the first 30 minutes of the observed evening shift indicates that distractions and interruptions are an important theme in nursing. As the nurse was starting her medication round, she was immediately interrupted by a phone call after which she attended to the needs of a patient who paged the nurse. Following this, when returning to the medication cart, a beeping sound was heard that indicated an empty infusion pump. This required a quick fix and on the way back to the medication cart the nurse was once more distracted. When the nurse finally put on the 'do-not-disturb' vest that nurses are required to wear during medication rounds, the nurse was asked a question by a service employee about the diet of a patient. Then, within 3 minutes of actually looking at the computer for medication specifications the phone rang. This conversation lasted for 5 minutes.

11:00	**a toilet flush from inside a patient room can be heard in the corridor**
	a conversation between nurse2 and patient? (inside patient room) can be overheard
11:05	**hissing noise from room X**
	patient in room Y is to be discharged, Nurse1 gathers things
	room Y is dark during discharge
	drip needle is removed
	no action is taken regarding the lighting
	a conversation nearby is not intelligible, intonation is clear however.
	relatives of patient Y are not here yet, this messes up the schedule of nurse1
	when a patient calls the nurse a red light turns on above the door case
11.10	**phone rings**
	nurse1 does not answer for a few minutes
	the call was from patient X
	nurse1 moves to room X
	room X is brighter than room Y, curtains open, lights on, different orientation
	nurse1 needs to get 'flushing bags' at another ward
	walk to neighboring ward's storage room and back
	due to the summer period they have some urology patients as well.
11.15	nurse1 changes flushing bag of patient X
	nurse1 chats with patient X while changing 'flushing bag'
11.20	nurse1 makes phone call
	nurse1 checks with the pharmacy about the medication that patient X is already on.
11.25	nurse1 continues discharge of patient Y
11.30	family arrives of patient Y
	nurse1 closes the curtain in the doorway to room Y
	family of patient Y gets instructions on medications and care
	it is warm in room Y and a bit stuffy
	nurse1 takes plenty of time to explain the medication, no signs of haste
	labels have to be red, but the lights are not switched on
11.45	nurse1 is still explaining
	many things have to be communicated to family Y
	nurse1 makes sure family Y correctly understands everything
	the doorway curtain is opened before nurse1 is finished talking
	nurse1 needs to get something from the medication room.
	three people are inside the medication room
11.50	the discharged patient Y leaves with his family.
	nurse1 goes around and tidies some things up.
11.55	nurse1 goes into the doctor's office
	nurse1 looks up the file of patient Z who is to be operated.
	they try to get all medication and measurements done before 12.00
	the computer system shows an action list
	nurse1 has 1 more medication task
12.00	**phone rings**
	nurse1: "' The phone drives me crazy!”
	the call is from an emergency necklace
	calls from emergency necklaces go out to all the nurses at the ward
	this call was not for nurse1
12.05	patient Z is not in the room
	Nurse1 is stressed: patient Z can be called for surgery any minute
	nurse1 tries to call patient Z
	nurse1 is still wearing the medication vest
	service1 asks for permission to disturb
	nurse1 allows disruption
	service1 needs to know about patient X's diet
	the floor has broad dark stripes
12.10	nurse1 intends to help out a colleague with medication
	phone rings
	nurse1 is interrupted by a phone call, does not help colleague
	patient Z is called to go to the OR
	patient Z is just entering the ward with a relative
	nurse1 tries to let patient Z move more quickly without being too stressed
	nurse1 and patient Z go into the room to get the patient ready
12.15	nurse1 "It is a little bit dark in here"
	patient Z: "yes, i closed the curtains because of the sun"
	nurse1 installs a drip
12.25	nurse1 takes patient Z to the OR preparation room

Figure 3-2 Fragment of the timeline created from the observation logs. Aspects related to sound are printed in bold.

3.2.3 **Emerging themes**

3.2.3.1 ***Task performance: Prospective memory in the nursing ward***

A typical aspect of the nursing job is to sequentially perform routine tasks that either require making important decisions or are based on these decisions. During the initial observation, examples were found indicating that, besides the well-known risks of medication errors, forgetting to execute a planned task could be a risk for the satisfaction and safety of patients. Looking into literature on the ability of nurses to prioritize tasks, to remember these priorities over a longer period of time and to remember to carry out each task at the right time led to the work of Potter et al. (2004; 2005) who studied the cognitive work of nurses. The term 'cognitive stacking' was used by these authors to describe the organizational skill of determining which tasks to complete and which to keep on hold. Planning, prioritizing and executing sequential tasks in the most efficient and patient-centered way requires a combination of decision-making and memory skills. The term stacking is also used by Ebright et al. (2003) who state that prioritizing and delegating based on anticipation of what might happen is an important part of the nursing job. Another term that is used to describe this cognitive process is 'prospective memory' which originates in cognitive psychology and refers to the memory that is used when remembering to carry out intended actions at an appropriate point in the future (McDaniel & Einstein, 2007). According to these same authors, whether or not an intended action is considered a prospective memory task is dependent on several parameters. First, execution of the intended action is not immediate. Second, the intended action has to be performed 'while doing something else' meaning that another activity, or a routine sequence of activities, has to be interrupted or changed in order to perform the prospective memory task. Third, there is a constrained window of opportunity during which the prospective memory task has to be retrieved from memory. Such a window can be characterized by time, an event (for example, passing a message when encountering a patient's family member) or an activity (for example, taking medication after finishing a meal). Lastly, the time frame needed to execute the intended activity has to be limited. Writing this thesis for example, was definitely not executed immediately after forming the intention, was embedded in ongoing activity (family and work life) and the window of opportunity was limited. Its execution did however require a long time frame which makes it unsuitable to be regarded as a prospective memory task.

An important aspect in prospective remembering is the role of cues. In the case of a time-based prospective memory task, a clock showing the time can be regarded as a cue that prompts retrieval of the task. If an alarm is set, this cue becomes even more obvious. When an intended activity is related to an event, as in the case of passing a message to a family member of a patient once you encounter that family member, the event in itself acts as a cue. Here too, additional cues may facilitate remembering, either intentionally or unintentionally. Examples are a written remark on the whiteboard in the patient room, or the family member could ask you whether there are things he or she needs to know.

Relatively little is known about prospective memory (PM) in nursing, though various sources do stress its importance for good performance (Dismukes, 2012; Fink, Pak, & Battisto, 2009; Fink, Pak, Bass, Johnston, & Battisto, 2010; Grundgeiger, Sanderson, MacDougall, & Venkatesh, 2009; Grundgeiger et al., 2013).

Questions regarding PM in nursing that remain unanswered are related to the number of tasks that a nurse has to remember, both at a certain point in time and during the whole shift. This is important information for the design of an experimental task that represents the work of a nurse. Insight is required in how, and when, intentions are formed, the type of PM tasks that are to be performed but also whether task omissions are actually related to PM failures (since deliberate omissions may also occur). One obvious reason to deliberately delay or omit an intention is a lack of (perceived) priority for that activity. Low task importance has been shown to affect PM performance (Kliegel, Martin, McDaniel, & Einstein, 2001). If several activities have to be performed in a short period of time, it can be argued that the activities with a lower priority are delayed or even omitted. This is in line with the Multiprocess Theory as proposed by McDaniel and Einstein (2000) according to which PM retrieval is supported by multiple processes. The processes referred to include continuous monitoring, spontaneous retrieval or a planful process of self-remindings. The process which is relied on in a specific occasion, and its effectiveness, is dependent on the characteristics of the PM task (such as the importance) the parameters of the PM cues (target distinctiveness, associativity of target with the intended action) and parameters of the ongoing task (such as task engagement or task demand).

To our knowledge, studies on t(he possible influence of environmental factors, such as background sound, on PM performance have not yet been published.

Based on the above, the decision was made to create a specific focus on PM and perceived priority for intended tasks in the data collection. With regards to PM this means that both the intentions that are formed by a nurse and the execution/retrieval of these intentions are defined as study parameters.

3.2.3.2 *Sound-task interaction: Auditory distraction*

The initial observation revealed that nurses are in constant information exchange with the environment. This supports our earlier claim about the importance of situational awareness in this setting. As a consequence of this openness and the dynamic environment, distractions and interruptions were observed as a key element affecting the course of the nurses' shift. They can be caused by various sound sources such as colleagues, other patients, phone calls or medical equipment. It has been suggested that interruptions and distractions are a prominent causative factor of medication errors (Biron, Loiselle, & Lavoie□Tremblay, 2009) and care omissions (Potter et al., 2004). A review by Biron et al. (2009) states that since empirical evidence on the relation between errors and interruptions is scarce and the definition of an interruption varies amongst different studies, it is an important topic to address in future studies. We decided to make this the scope in terms of sound-task interaction.

3.3 Final data collection

3.3.1 Study design

The chosen approach combines qualitative observations and questionnaires with calibrated audio recordings. Non-participant observation was performed to map nurses' activities, locations, the sources of sound events and their locations. In addition, the think-aloud method (Fonteyn, Kuipers, & Grobe, 1993) was applied to gather information on the nurse's planning, decision making and reaction to the sound environment. An individualized questionnaire per nurse, based on the data collected during each observation, was used to measure the nurses' perception on PM execution and task priority.

Observations were carried out by two individual researchers (A and B) with different backgrounds. The rationale for this multi-disciplinary approach was to limit the possibility of a one-sided perspective. When studying the influence of sound on people in their work environment, studies are often conducted from either a psychological or an acoustic point of view. Knowledge and experience from inside the population under study is often lacking. Observer A was a graduate student in nursing science, with several years of working experience as a registered nurse. Observer B, the author, has a background in acoustics and specializes in the effect of sound on people.

3.3.1.1 ***Visual non-participant observation and the think-aloud method***

Non-participant observations, during which the two individual researchers observed one nurse during the first three hours of a day shift were carried out in two surgical wards of a Dutch top-clinical hospital. An important detail is that the hospital was newly built in 2013 and was designed with the ‘healing environment’ (Huisman et al., 2012) concept in mind. This means that the way of working and the building itself represent the current state of the art.

Twelve nurses were asked to do their job as usual and ignore the two observers as much as possible, with one exception. This exception is the use of the Think-Aloud method (TA) which was applied to capture the nurse’s intentions to execute tasks. As this method requires the participant to speak out every thought occurring in his or her short-term memory, it was expected that intentions for future actions are spoken out loud and could, therefore, be logged by the observer (A). Furthermore, as audio recordings were made, the spoken out intentions should be traceable in the audio recordings. The TA method has been used in nursing studies before, usually to gain insight into clinical reasoning (Forsberg, Ziegert, Hult, & Fors, 2014; Johnsen, Slettebø, & Fossum, 2016) but to our knowledge it has not been used with regards to PM. Another benefit of using the TA method is that distractions could be more easily detected. It was expected that by asking to think out loud, deviations from a current line of thinking could be logged. Being able to simultaneously capture formed intentions and distractions was one important reason for adopting the TA method. A second, equally important, reason was that by using TA we did not create a bias towards noticing sound events or trying to remember and retrieve formed intentions.

Observer A kept an activity log of the nurses’ actions. Every activity carried out by the nurse was logged with a time stamp (maximum resolution of 1 minute). Furthermore, every intention that was spoken out by the nurse was logged. Every occasion in which the nurse spoke out the intention of performing an activity during the shift, that was not immediately followed by execution was considered a PM intention. Apart from the intentions which are captured through spoken out thoughts, intentions could also be captured if a verbal promise was made by the participating nurse to a patient, visitor or colleague. Finally, an intention was also captured when a current activity of the nurse was interrupted and the nurse turned away to perform another activity. In that case, the assumption was made that the nurse formed the intention to return to the original task, even if this intention was not spoken out. For each way of capturing an example is given in Table 3-1.

Observer B had a different focus during the observations and was responsible for the audio recordings. A log was kept containing entries for prominent sound events. A description of each event was logged and if a direct consequence could be seen related to an event this was logged as well. Each entry on the observation model used by observer B contained information on the nurses’ location and the location of the sound source (if detectable). Patient rooms were numbered and abbreviations were used for all other types of rooms. Observer B also created entries for PM intentions, in order to increase the face validity of the observation.

Table 3-1 Examples of PM intentions measured during the observation

Description of the situation	PM intention	Captured trough
The nurse is reading a patient (PX) file at the start of a shift. He/she speaks out loud that the patient needs antibiotics to be administered at time Y.	PX: Administer antibiotics at Y.	TA method
The nurse is asked by a colleague (CX) to sign off medication while being with a patient (PY). He/she responds by saying he/she will be there in a minute.	CX: Sign off medication after finishing task at PY	Verbal Promise
The nurse is changing the bedsheets of a patient (PZ) who is taking a shower when he/she is called away to assist a colleague with another patient. He/she leaves the bed unmade.	PZ: Finish making the bed.	Interrupted task

3.3.1.2 *Questionnaire*

An individualized set of questions was used to measure the participants' perceived priority of intended tasks and their perception on whether intended tasks had actually been carried out at the appropriate time, were delayed or omitted. Besides demographical data such as age, gender, and working experience, the template consisted of two parts. The first part contained two questions. In the first question, the participant was asked to rate the perceived workload during their current shift on a visual analogue scale of 10 centimeters. The left-end of the scale was marked 'low' and the right-end was marked 'high'. The second question was regarding the participants' priority for each intended task. The template for the questionnaire was identical for each nurse, however, the content varied as each nurse formed different intentions. The template was created such that each logged PM intention during the observation represented one item in this question. The nurse was asked to rate the priority of each PM intention on a visual analogue scale of 10 centimeters. Again, the left-end of the scale was marked 'low' and the right-end was marked 'high'.

The second part of the questionnaire contained only one question. The template for this question was similar to the second question in the first part of the questionnaire as each logged PM intention during the observation represented one item. For each item (PM intention) the nurse was asked to answer whether it was omitted, executed in time or executed too late. If a task was omitted or executed too late, the nurse was asked to answer whether the delay or omission was deliberate or not. A PM failure was defined as a non-deliberately delayed or omitted PM task. For deliberately omitted or delayed intentions, the nurse was asked to provide a reason.

3.3.1.3 *Audio recordings*

In-ear audio recordings (sample frequency 48000 Hz) were made by researcher B to record the verbalized thoughts and the sound environment in which each nurse performed the shift. The in-ear microphones were worn by researcher B, who tried to stay as close as possible to the participant without obstructing care. This way, the nurse did not have the responsibility of carrying the recording device while the recorded sound environment is still very similar to the sound environment of the nurse.

3.3.1.4 *Definitions of study parameters*

Several study parameters were defined, the definition of each is described in Table 3-2. In the case of disagreement regarding intentions between the researchers, the intention was included in the individualized questionnaire and discussed at a later stage in time.

Table 3-2 Definitions of study parameters and measurement method. The first column relates to whether the parameter was measured through observation (O) or by the questionnaire (Q). The second column indicates which observer was responsible for the data collection.

How	Who	Parameter	Definition
O	A	Activities	Each activity, not necessarily related to care, carried out by the nurse.
O	A/B	PM intentions	Each intention observed through TA, a verbal promise or an interruption
O	A/B	Interruptions	Every activity as defined above which is interrupted in order to start another activity
O	B	Distractions	Every (visible or audible) occasion in which the nurse's attention is drawn away from their current activity.
O	A/B	PM load	The amount of intentions stacked at a given moment in time. (1 minute resolution)
O/Q	A/B	PM failures	A PM failure occurs if an intended action is not remembered at the planned time of execution. To measure PM failures, both the observations and the questionnaires are required.
O	B	Sound events	All noticeable (during observation and offline analysis of recorded) sounds.
O	B	Nurses' locations	The whereabouts of the nurse during the observation period
O	B	Sound events' locations	The source location of each noted sound event
Q	A/B	Priorities	The participants' perceived priority of each PM intention
Q	A/B	PM execution	The participants' perceived task execution of each PM intention, which is either in time, deliberately delayed or omitted, or undeliberately delayed or omitted.
Q	A/B	Reasons for delays and omissions	The reason provided by participants for each deliberately delayed or omitted PM intention.
O	A	Cues	Any reminder the nurse created for future activities. For example, a written note or purposely leaving an item somewhere in sight as a reminder.

3.3.2 **Participants**

The study population consisted of a convenience sample of 12 (11 female, 1 male) registered nurses, working in one of the two selected surgical wards in the hospital in the Netherlands. It was aimed at recruiting participants using maximum variation sampling on age, sex, level of education and experience (total and at the particular ward), but due to the limited number of nurses working at each ward and the study's dependence on their willingness to cooperate only 6 nurses were found in each ward to volunteer. Inclusion and exclusion criteria are shown in Table 3-3. Due to a problem with the measurement equipment, audio recordings of 2 participants could not be used. The recordings are complete for 8 participants, for another 2 participants a part of the audio data is missing. The activity and sound logs, as well as the questionnaires are complete for all 12 participants.

The average age of the participants was 26.2 (sd = 3.0) years and their average working experience as a registered nurse was 4.7 (sd = 3.1) years.

Table 3-3 Inclusion and exclusion criteria for the participants.

Inclusion	Exclusion
Native Dutch speaking nurses.	Nurses with reported hearing disorders.
Nurses with at least 1 year working experience.	Nurses who are aware of the exact purpose of the study.
Nurses working at their regular ward.	Students.

3.3.3 Equipment

During the observations, both researchers used a clipboard holding printed sheets with the predetermined observation model. Two identical simple digital clocks, synchronized and showing the time in minutes were used by both observers to create the time stamps on the observation models.

A TASCAM DR-40 audio recorder was used in combination with 'MS-TFB-2 Sound Professionals In-Ear Binaural microphones' to record the sound environment. All recordings were made with the same equipment, calibration recordings were performed before the first recording and after the last recording.

3.3.4 Recruitment and consent

One week before the final data collection, a short presentation about the study was given during a monthly team meeting in both wards by the observers to recruit volunteers. After the presentation, an invitation letter was given to all interested nurses of the particular wards who were meeting the inclusion and exclusion criteria. More comprehensive information, including the TA instruction and a permission-form for data gathering was provided to the final six volunteers from each ward. The procedure of retrospective informed consent was used, since the participating nurses could not be informed of the exact study aim, specifically with respect to PM, prior to the observation, as this could affect the results. Before participation, the subjects gave written permission for data gathering, but not for the use of these data. After completing the first part of the questionnaire, they received information on the study aim, signed the informed consent and thus gave consent to the use of the gathered data.

3.3.5 Ethical considerations

An external Medical Ethics Research Committee has reviewed the study protocol and determined that the Dutch Medical Research Involving Human Subjects Act does not apply for the current study (reference number WAG/nt/16/034630). Furthermore, the study was approved by both the involved hospital's executive board and the internal ethics committee. Since no patients or visitors were actively involved in the data collection, but the audio recording does contain patient data, information letters were distributed amongst the patients the day before each observation. Patients were informed both verbally and through the letter that they could refuse to allow the recording of audio within their vicinity without any consequences. The gathered data, which consists of the audio files, activity and sound logs and the completed questionnaires is stored on a secured server. Access to the data is restricted to the author and the promotor. The data will be stored until 7 years after the author's doctoral defense.

3.3.6 **Procedure**

A pilot observation was conducted with one nurse prior to the final data collection for three reasons. The first reason was to get the researchers acquainted with the protocol. The second reason was to check whether PM intentions could actually be captured by using the TA method and whether they were recognized as such by the nurse in the questionnaire. The last reason was to allow for any adaptations due to unforeseen reasons. One adaptation was required: it was observed that some routine activities, such as the medication round and ADL were implicitly planned by the nurse without speaking them out loud. Based on this, it was decided to ask the participating nurse about the general planning of the day after having read the patient files and the change of shift transfer. This minor intervention allowed the researcher to log these implicitly formed intentions.

Next to this adaptation, one addition was made to the protocol. Due to the early start (07:00 AM), each participant was contacted by phone by the author on the day prior to observation. It was made sure that all instructions, which were provided at the team meeting and by email, were clear and the participants were given the opportunity to ask any additional questions.

Observations took place in February and March 2017. They were conducted on weekdays only, as fewer surgeries are scheduled during weekends. They were conducted during morning shifts and started at the beginning of each participant's shift at 07:00 AM. Starting the observation at the beginning of a shift assumes a PM load of zero. Another reason to observe the first hours of the morning shift was that, in this hospital, morning activities are reasonably standardized. They include patient checks, medication round, Activities of Daily Living (ADL) care and medical rounds (doctor's visit). The observation time was limited to three hours for three reasons:

- Logging all activities, intentions and sound events requires a high focus from the observers. During the pilot study it was confirmed that it became harder to stay focused after three hours of observation.

- Speaking out every thought (TA) is a burden for the participants. Limiting the observation time to three hours reduces that burden.

- The researchers need time to process the list of captured intentions in order to conduct the questionnaire during the nurses' lunchbreaks.

At both wards a short coffee break is scheduled for the nurses around 10:00 AM as part of their daily routine. This provided a natural break point in the shift to stop the observations. The observations were therefore always continued until this break, which means that it could be a little earlier or a little later than 10:00 AM. At the end of the observation the participant was instructed to contact the researchers when they would start their lunchbreak during which the individualized questions would be presented to the participant. During this lunchbreak, the nurse was asked to provide a blinded (by removing patient and staff names and dates of birth) copy of any written notes that were made until that point in time. These notes were used to log whether a reminder (cue) was created for a logged PM task.

Both researchers used the time between observations and questionnaire presentation to create the list of intentions.

Each nurse was first asked to answer the question on priority for each intended task. After this, the participant was informed of the study's exact purpose and asked whether tasks had been executed or not. This order was chosen to reduce the chance of nurses' rating the priority for delayed or omitted tasks as lower. For each participant it was emphasized that the results would be anonymized and that the questionnaire was not intended to evaluate or appraise them. A timeline of the followed procedure for each participant is illustrated in Figure 3-3.

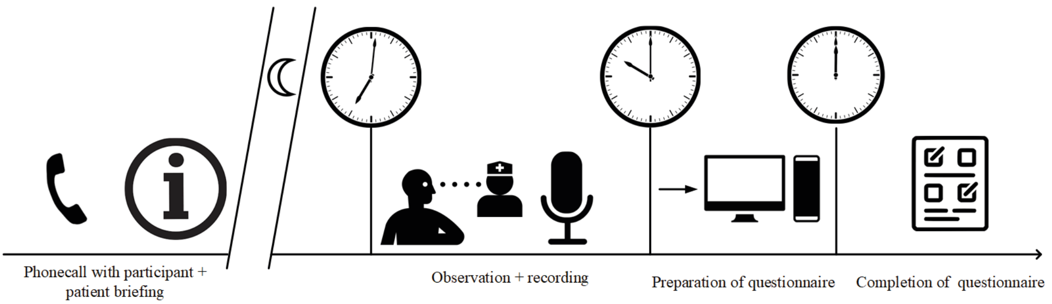


Figure 3-3 Timeline of the procedure.

3

3.3.7 Analysis

The observations produced four different data sets, consisting of the audio recordings, the observation logs, the questionnaires and the notes produced by the nurses. MAXQDA 12 (Kuckartz, 2007) and SPSS 25 were used to analyze the data. The data analysis is further described in **Chapters 4 and 5**.

3.4 Overview of results

To provide a general insight in the available data, an overview of one shift is presented in Figure 3-4. Using MATLAB, the A-weighted energy-equivalent sound pressure level was obtained in 10-second time frames. Coded segments were exported from MAXQDA to create a timeline that shows the participant's location, activity, the moments on which an intention was logged, periods of distraction, interruptive activities, and pagers and phone calls The results of the questionnaire are processed as well; red markers are intentions that were, according to the participant, omitted (not executed); yellow markers are intentions that were executed too late and green markers were executed in time. For each delay and omission, the row below shows whether it was a PM failure (red) or a deliberate delay/omission (grey). The PM load is displayed as well.

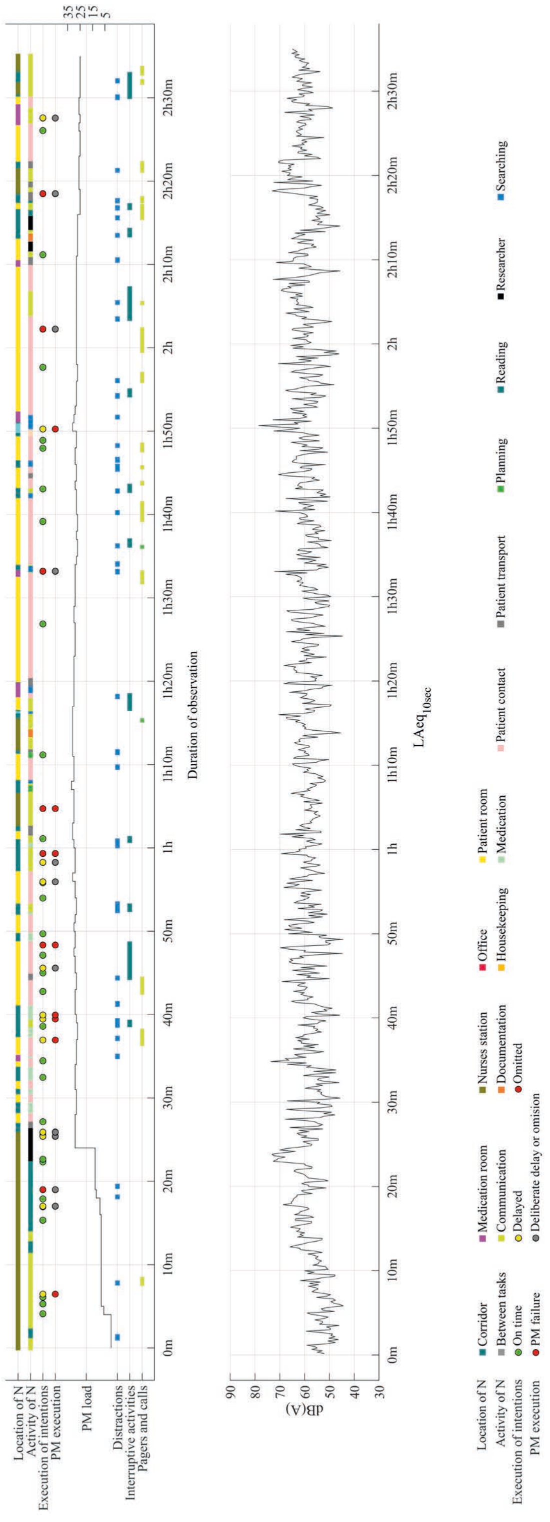


Figure 3-4 Overview of collected data from one observation. The horizontal axis represents a timeline of the observation. The vertical axis represents the various study parameters.

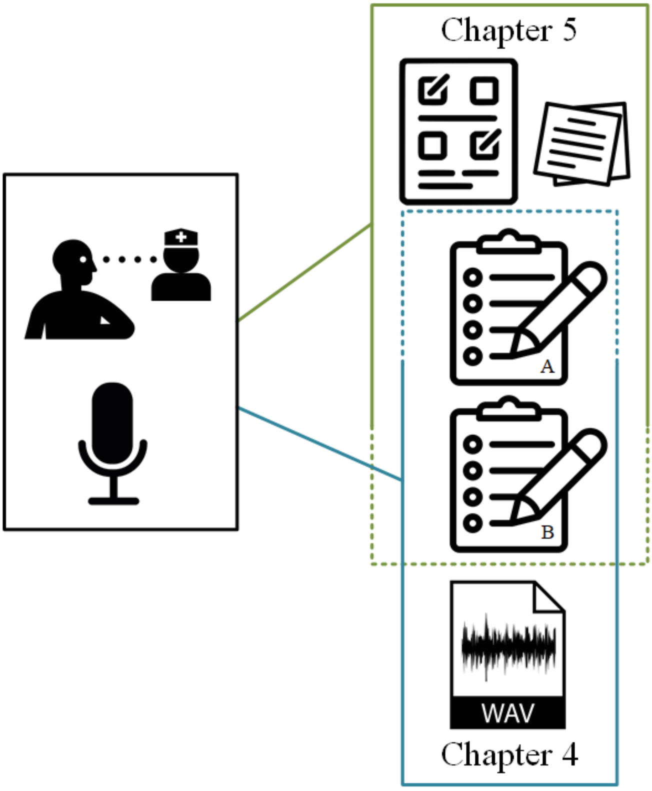


Figure 3-5 Overview of the datasets resulting from the observation. The audio files and observation log B are the main datasets used in Chapter 4, aided by observation log A. The questionnaire data and observation log A are the main datasets used in Chapter 5, aided by observation log B.

3.5 Concluding remarks and outlook

The aim of the described method was to collect field data which help us to bring future research on the effect of sound on task performance closer to reality. Three challenges were described that are, in our interpretation of the current literature, preventing an adequate translation from results of many laboratory studies to real environments. As can be seen in Figure 3-4, the observations led to a rich data collection.

The results and the analysis of the data that were collected through this observation study will be a discussed in light of the three challenges in **Chapters 4 and 5.** Figure 3-5 demonstrates an overview of the available data and the corresponding chapters in which their analysis is presented.

Distraction during different nursing activities in a nursing ward

4

4 Distraction during different nursing activities in a nursing ward

Knowledge on the influence of the sound environment on task performance can be used to improve working conditions and reduce the risk of human errors and lack of productivity. For laboratory studies on the effect of sound on task performance to be meaningful from an applied perspective, the experimental task, the sound conditions and the role of sound for the task must be representative for the work environment under study. This chapter presents the exploration of the influence of sound on task performance by simultaneously gathering knowledge about the activities of the target group, and the sound environment at their workplace. In this exploration, not only the sound environment's potential for distraction during separate, cognitive tasks, but also the content of actual distractions in the context of the job in its entirety were studied. Data was collected through non participant observations combined with audio recordings. Based on the analysis of results, critical combinations of task and sound environment were identified. Furthermore, a conflict between the need for situational awareness and task concentration was observed. The information gathered through this observation can help to understand where distractions originate and whether they are necessary for the care of patients or should be eliminated.

4.1 **Introduction**

The physical environment in which a task is performed, and in particular the sound environment, is one of many aspects that can affect our ability to concentrate on that task. In the past 40 years, an increasing amount of laboratory studies have been performed, indicating that auditory distraction can lead to a decreased performance of the primary task (Beaman, 2005; Dalton, B. H. & Behm, 2007; Hughes, 2014; Liebl & Jahncke, 2017; Schröger, Giard, & Wolff, 2000). One important reason to study the effects of sound on performance, is to gain insight into the effect of the acoustic environment on performance in actual workplaces. Such insights can help to improve working conditions and reduce the risk of human errors and lack of productivity.

Relatively little is known on the influence of the sound environment on the performance of healthcare professionals, nurses in particular. Ensuring patient safety is an important task that comes with great responsibility. Medication errors, errors in judgement or missed care, all of which can be the result of human errors (Aarts, Craenmehr, Rosemann, van Loenen, & Kort, 2019; Jones, T. L., Hamilton, & Murry, 2015; Kohn, Corrigan, Donaldson, McKay, & Pike, 2000; Tang, Sheu, Yu, Wei, & Chen, 2007), can have serious consequences for the health and safety of patients. Therefore, in the context of creating healing environments, the sound environment at the workplace of this target group should not be overlooked.

For laboratory studies on the effect of sound on task performance to be meaningful from an applied perspective, an experimental task must be representative of the tasks that are performed in the work environment of interest. This is due to the task dependency of a sound effect (for an elaboration, see **Chapter 2** (2.4) and **Chapter 3** (3.1)). Furthermore, experimental sound conditions (the type of sound sources, their behavior over time and even their spatial orientation) should resemble those that can be found in actual workplaces (Beaman, 2005), and, as discussed in **Chapter 2**, the difference between experimental sound conditions should be feasible results of realistic interventions. This calls for unique combinations of workplace characteristics to be captured in an experimental design.

Not only the design of an experimental task and the manipulation of experimental sound conditions require careful selection. In the design of laboratory studies concerning the effect of irrelevant sound, sound is, without exception, communicated to be irrelevant for the primary task. Participants are instructed to focus on an experimental task and ignore the sound they are exposed to during the task. Sometimes, the irrelevance of the sound is emphasized by promising the participants that they will not be asked any questions about the content of the sound environment during the experiment. Of course, this allows for a pure analysis of the effect of sound on a very specific task and adds to the understanding of cognitive processes. In applied settings, however, sounds may be relevant for either the primary task, or for the more complex combination of tasks that a job entails. Over-hearing a conversation between two colleagues in an open-office while working on a complex problem, for example, may be distracting, but could also inspire to think about that complex problem in a different way. In a hospital, fully ignoring the sound environment in the ward during medication administration may lead to fewer distractions, but could have serious consequences for the patients in the ward. In the context of nursing, the interaction between the task and the sound environment, and the relevance of the sound environment for the job is of particular interest.

Therefore, a first step in the exploration of the influence of sound on task performance is to gather knowledge about the cognitive activities of the target group, and the sound environment at their workplace. Moreover, such an exploration should not only take into account the sound environment's potential for distraction during separate cognitive tasks, but also study the content of actual distractions in the context of the job in its entirety.

4.1.1 Aim and focus of the study

This chapter presents an exploration of auditory distraction in an applied setting, focusing on nurses. An analysis of the actual sound environment in a modern nursing ward and the distractions caused by sound events during different nursing activities has been performed.

While, on a behavioral level, the generalization of laboratory studies to applied settings must be done with caution, valuable insights on the distraction potential of sound environments can be derived. According to the duplex mechanism account of auditory distractions, two mechanisms are responsible for performance impairment when subjected to irrelevant sound, interference-by-process and attentional capture (Hughes, 2014). Whether interference-by process occurs is very task dependent. Performance on a semantic task is more likely to be impaired by meaningful speech than by non-meaningful speech (Jones, D. M. et al., 1990). The performance on tasks that require serial ordering processes is impaired by any sound with acoustical variation between one segment and the next (Hughes, 2014). Attentional capture is considered to be less dependent on the task type, and could happen when a violation of the (subconsciously) expected sound environment occurs (Dalton, P. & Hughes, 2014; Vachon et al., 2017). Based on the above, the presence of background speech and its intelligibility, and any notable (standing out from the background) sound events are expected to be of interest in our exploration.

The primary activities and locations of the nurse are logged to gain insight into the sound environment during different cognitive tasks. Furthermore, the amount, duration, and the origin of distractions caused by sound in the ward environment are quantified. To gain insight into the role of sound, the content and context of each distraction are logged. It is our expectation that critical combinations of tasks and sound environments can be identified based on this exploration. Moreover, it could aid the design of new, ecologically valid, studies.

4.2 Method

4.2.1 Data collection

An extensive description of the study design and the hospital in which data collection took place can be found in **Chapter 3**. The data that was used in the current analyses are the five complete audio recordings from one ward and the two observation logs from the individual observers for each of these five observations (see Figure 3-5). The decision to include the data from only 5 observations was based on the time required for analyzing and coding the audio files. The selection was based on the availability of complete audio recordings for observations that took place in one (orthopedic) ward.

4.2.2 Data analysis

Data analysis was conducted by the author by coding the audio aided by the two observation logs created by researchers A and B (see **Chapter 3**, section 3.3.1) MAXQDA 2018 was used to code fragments of the audio file based on the available information. The observation log created by researcher A contains a detailed description of the shadowed nurse's activities. Fragments were coded based on the categorization in Table 4-1, which is an adapted version of the categorization used in Wolf et al. (2006). The observation log created by researcher B contains information on the nurses' location throughout each observation, sound events and the nurses' visible responses to these events (if any). A location code was assigned to all audio fragments based on the categorization in Table 4-2.

To measure and log distractions a combination of methods was employed. Any task interruption (a halt of the current activity, in order to start another) caused by a sound event, and therefore preceded by a distraction, was logged. This, however, excludes distractions that are not acted upon. To be able to log these, invisible, distractions, the Think Aloud method was used (Fonteyn et al., 1993). As described in **Chapter** 3 (section 3.3), the shadowed nurses were instructed to think aloud during the observations. This allowed for a more detailed search for thoughts that deviated from their current activity. In our analysis, a fragment of the audio file was coded as a capture of attention, any time the nurse's line of thought deviated from the task that was being performed at that moment, that could be linked to a sound event in the near past. Deviations that were not clearly linked to a sound event were not coded, the nurse saying hello to a colleague walking by for example, could be due to footsteps, but could also have been a visual distraction. Third, during the observations, behavioral changes of the nurse were logged. If the observation log contained a comment of the nurse looking at her pager, or looking up from a task in the direction of a sound event, this sound event was coded as a capture of attention. The coding decision process is schematized in Figure 4-1.

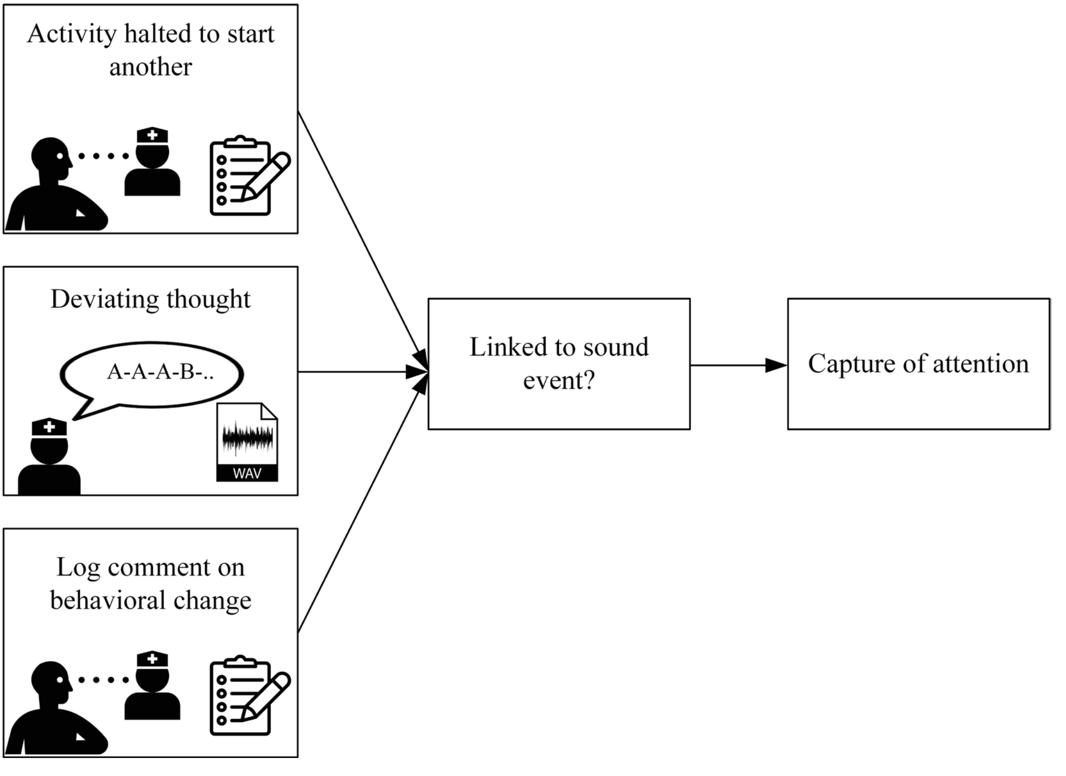


Figure 4-1 Distraction coding decisions

In the coding process, each distraction was tagged with the source of the distraction, being directed speech, background speech, a pager, a phone call or 'other'. Directed speech, pagers and phone calls were considered to be intended, whereas background speech or 'other' were not.

If the distraction led to an activity that was not originally planned for that moment, this activity was coded as an 'interruptive activity'. If the nurse was 'between tasks' when the distraction occurred, and the next activity was not known to the researcher, a new activity was not considered to be interruptive. The reason for this is that such a 'new' activity, though not verbalized, may have been exactly what the nurse had planned.

4

To explore the ‘distraction potential’ of the sound environment, potentially distracting sound events were defined and specified. Fragments containing ringing phones or pagers, intelligible background speech and alarms were coded with a specific code. Unintelligible background speech was not coded. To be considered as intelligible, a fragment had to contain more than three consecutive intelligible words. Any other sudden sounds such as patients coughing or crying while the nurse was not in their room, doors closing loudly, carts, trolleys passing by, loud footsteps and undefined mechanical sounds were coded as potential distraction, but not further specified. Sounds that were produced by the nurses themselves and the patients or colleagues they were interacting with were not coded. This is also the case for radio or television that was audible in a patient’s room when interacting with that patient.

A contextual analysis was made for each observed distraction, based on the origin of the distraction, the observed behavior of the nurse and the possible consequences for the nurse’s task. It was determined whether the distraction was intended or unintended, and for each unintended distraction it was determined whether it provided useful information related to patients, planning or other care related aspects. This analysis was performed by the author only, due to the sensitivity of the data.

Table 4-1 Categorization of nursing activities. Based on Wolf et al. (2006) and adapted based on observation results.

Activity code	Description	Examples / clarification
Between tasks	The time between two activities, or actively waiting.	Roaming the corridor without a specific purpose, remaining in a room after an activity without immediately announcing (TA) or starting a new activity. The time between finishing a conversation with a colleague and entering a patient room to see a patient.
Communication	Any verbal interaction with a colleague or a visitor.	Change of shift transfers, information exchange with colleagues, doctor's round.
Documentation	Any logging of information, either digitally or on paper.	Entering the results of measurements or observations in the computer. Reporting a mistake. Posting a question in the EMR for a colleague.
Housekeeping	Cleaning and storing items.	Placing back used items in a medication room or rinsing room, cleaning a toilet chair, making a bed when a patient is in the shower.
Medication	Preparing, checking and/or collecting medication.	Taking medication from a mobile medication cart, preparing an infusion, calculating the amount of required opiates, double-check a colleague's medication preparation.
Patient contact	Any interaction (direct contact with) with a patient.	Administering medication to a patient after preparing it, inspecting a wound, helping a patient on the toilet, changing a patient's position.
Patient transport	Taking patients to and from the ward.	Taking a patient to go into surgery. Getting a patient from recovery.
Planning	Actively planning future activities (without reading the EMR)	Time in between activities during which the Nurse plans future activities.
Reading	Reading from the EMR	Reading patient information from the computer, this includes active planning based on that information.
Searching	Searching for or collecting items or people in the ward. This includes purposely walking to and from the place.	Collecting items for wound care. Looking for a colleague. Collecting items for a discharge package.

Table 4-2 Categorization of locations

Location code	Description
Corridor	Any place in the ward corridor, including the counter and the coffee corner.
Patient room	All patient rooms and attached bathrooms.
Nurses' station	The enclosed nurses' station.
Office	One specific office in the ward used by nurses and doctors.
Medication room	The dedicated medication room in the ward.
Other	The linen room, a rinsing room, the toilet, a meeting room
Off Ward	Any location that is outside the ward: elevators, other corridors, hot floors.

4.3 Results

4.3.1 Overview of results per observation

A total of 15 hours and 11 minutes of recorded audio was analyzed for the 5 selected participants. All participating nurses were female, with an average age of 27 (S.D. = 3.8) and an average nursing experience of 3.7 years, ranging from 7 months to 9 years.

The results of the simultaneous analysis of each nurses' locations, activities, observed distractions, interruptions and potentially distracting sound events are visualized in the timelines in Figure 4-2 through Figure 4-6. The bottom two bars in each timeline, showing the times at which intelligible background speech was present and the potentially distracting sound events, have a darker shade when the coded fragments are more dense.

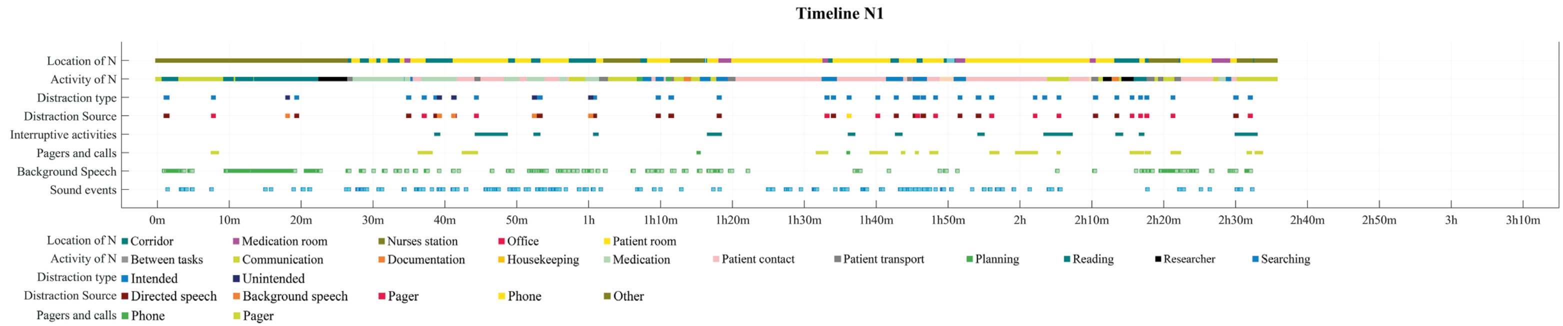
A typical pattern of nursing activities can be seen in the timelines. At the start of the shift, each nurse spent a longer period of time in one location, either the nurses' station or the office. During this period, the main activities are reading and communication. To get familiar with the patients already admitted to the ward and those that will arrive that day, they read the EMR and receive a verbal change of shift report from the colleague who has worked the nightshift. Based on the information they receive, they start forming intentions for the care activities they want to perform during the remainder of the shift. After this initial period in one room, the nurses' timelines show an alternating pattern between mainly the corridor and patient rooms (location) and communication and patient care (activity). The nurses in this ward cared for a number of patients (up to 10) in pairs and divided their tasks. For example, one nurse would be responsible for ADL (activities of daily living) care, while the other would do rounds with a doctor. The typical activities that were to be done each morning were a medication round, taking vitals, doctor's rounds, ADL care, preparing patients for surgery and admitting patients to the ward.

From the timelines in Figure 4-2 through Figure 4-6, a clear difference in activity and location patterns can be read. The timelines of N1, N2 and N5, the latter with the exception of the middle part, are more fragmented than the timelines of N3 and N4, meaning there was more task switching. Especially the timeline of N3 shows longer periods in one patient room, performing patient care. This particular nurse was occupied with a long admission in the early morning and took her time during ADL care later in the shift.

The timelines indicate that the nurses are exposed to almost continuous background speech at the beginning of their shifts, when focal tasks such as reading the EMR and listening to a change of shift report (coded as 'communication') are performed. These tasks are typically performed in the nurses' station or a small office. A difference between the intelligible speech fragments at the beginning of the shift compared to the remainder of the shift is that at the start of the shift, both the nurse and the background speech sources are in the same room for a longer period of time, causing full conversations, dialogues, to be heard in the background. The topic of these conversations include discussions about present and past patients, organizational issues, verbal change of shift reports and social aspects. Later on in the shift, in most cases, either the nurse or the sources of background speech are moving, and at a larger distance, causing the nurses to hear fragments of conversations. These fragments are mainly part of conversations between colleagues and patients, about their food preference for example or explaining care, and between colleagues.

Common sounds that were audible in the audio recording and logged in the observation model were the opening and closing of the medication room door, food trolleys, the bedpan washer, patients coughing loudly and medical equipment such as a bladder scan or a commode chair passing by. These sounds occurred throughout the observations. Absence of notable sound events generally only occurred when the nurse was in an enclosed room.

There is no clear pattern in interruptive activities that can be read from the timelines. The interruptive activities are generally short encounters between the nurse and a colleague, or the nurse responding to a patient call.



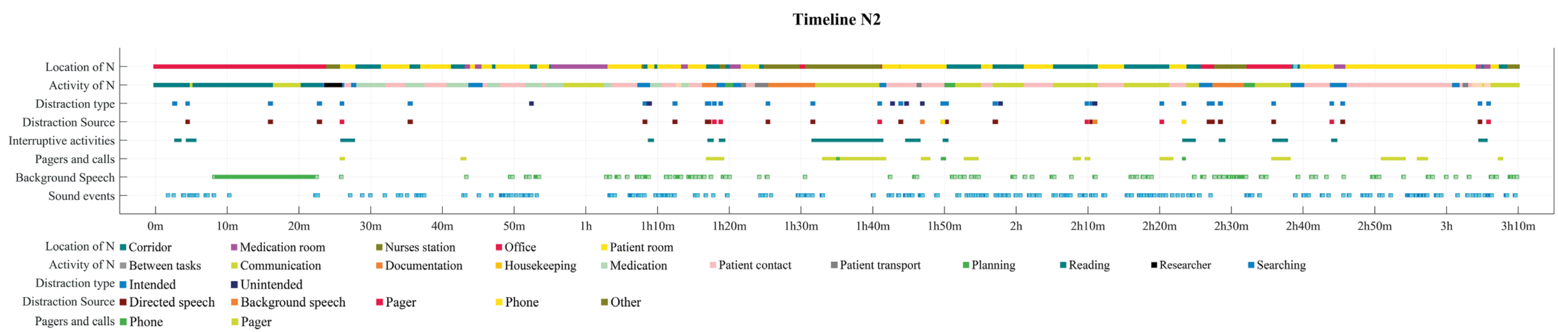
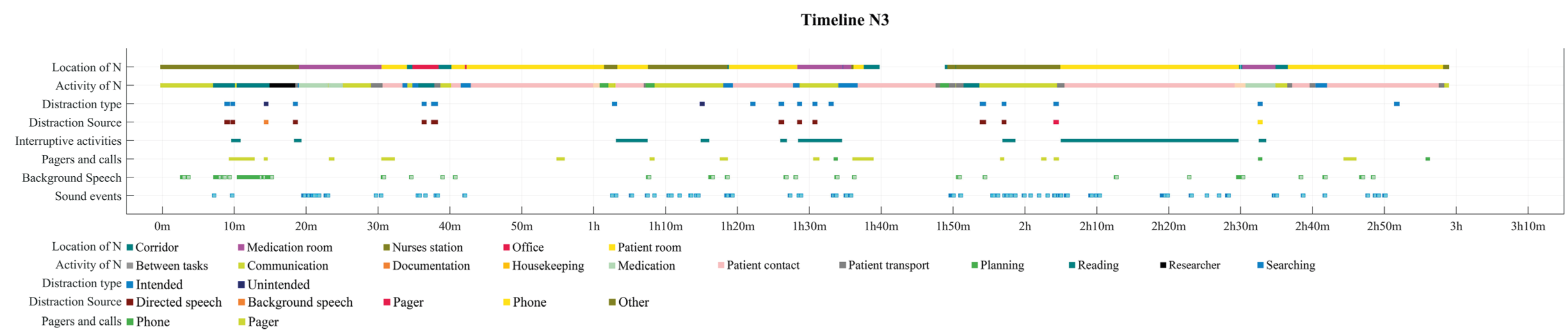


Figure 4-2 Timeline of the Nurse’s (N1) location, activities, distractions, interruptive activities, pagers and calls, intelligible background speech and notable sound events. The time on the horizontal axis represents the duration of the observation which started around 07:00 AM.

Figure 4-3 Timeline of the Nurse’s (N2) location, activities, distractions, interruptive activities, pagers and calls, intelligible background speech and notable sound events. The time onthe horizontal axis represents the duration of the observation which started around 07:00 AM.



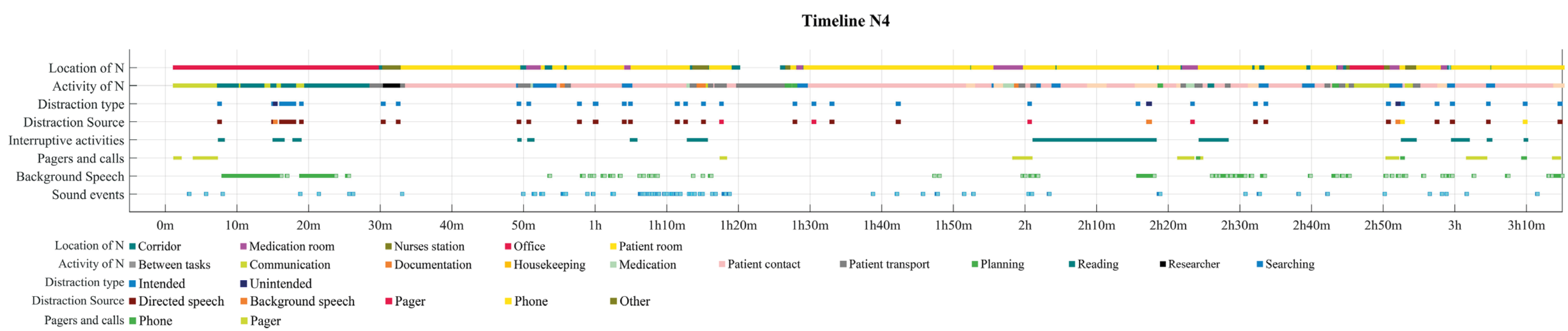


Figure 4-4 Timeline of the Nurse's (N3) location, activities, distractions, interruptive activities, pagers and calls, intelligible background speech and notable sound events. The time on the horizontal axis represents the duration of the observation which started around 07:00 AM.

Figure 4-5 Timeline of the Nurse's (N4) location, activities, distractions, interruptive activities, pagers and calls, intelligible background speech and notable sound events. The time on the horizontal axis represents the duration of the observation which started around 07:00 AM.

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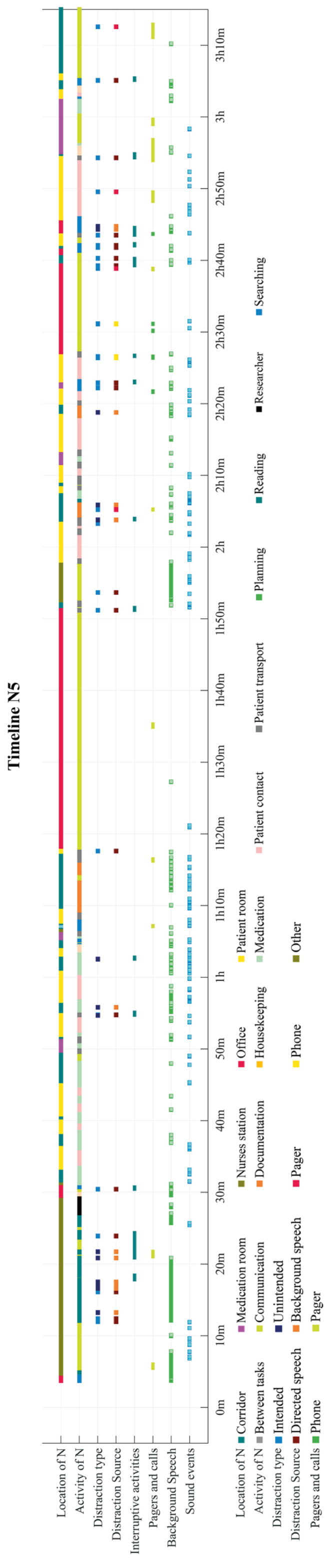

Figure 4-6 Timeline of the Nurse's (N5) location, activities, distractions, interruptive activities, pagers and calls, intelligible background speech and notable sound events. The time on the horizontal axis represents the duration of the observation which started around 07:00 AM.

4.3.2 **Activities and locations**

Figure 4-7 and Figure 4-8 show the total time spent on the different nursing activities and in the five most prominent locations for each nurse. On average, the nurses spent most of the observed time interacting with patients and communication. For each activity and location, the percentage of time during which intelligible background speech was present is provided in Table 4-3. It shows that, on average, the nurses were exposed to intelligible background speech for more than half of the time they spent reading the EMR. The locations in which the nurses were exposed to most background speech were the nurses' station and an office. The number of notable sound events and the number of pager calls are presented in Table 4-4 and Table 4-5. In total, 129 notable sound events were logged and 70 pager calls. As could be expected, the highest number of notable sound events were logged in the corridor and patient rooms.

An overview of the coded distractions during the different activities and in the different locations is shown in Table 4-6. In total, 178 distractions were observed of which 146 (~82%) were intended and 32 (~18%) were unintended. During the activities 'reading' and 'searching' the most intended distractions occurred, with almost 20 and 30 distractions per hour, respectively. Activities during which the most unintended distractions were logged are reading, medication and searching, with more than 5 observed distractions per hour on average.

As shown in Figure 4-9, directed speech is by and large the most common source of distractions. Table 4-7 and Table 4-8 in section 4.3.3 present a cross-section of these observed distractions in context. There is a mismatch between the number of pager calls and the number of distractions caused by pagers. The first reason for this is that not all the logged pager calls were intended for the nurse, it could also have been the pager from a colleague. A second reason is that nurses often did not pay visible attention to their ringing pagers. On some occasions they checked the origin of the call (immediately or after a while) but did not take action to stop the ringing sound. A possible explanation could be the call lights above the patient rooms' doors that were clearly visible from the ward corridor. A nurse walking around could easily spot which patient was calling without specifically looking. Not stopping the sound could be due to acceptance or 'getting used to' the pager sound. In the timeline in Figure 4-3, at approximately 1h33 minutes into the observation, a pager that was not intended for the observed nurse kept ringing during a period of 11 minutes. This nurse was discussing a patient with a doctor, and shrugged when the doctor wondered why the pager kept ringing while saying that it was not her pager.

Background speech was a common source of unintended distractions. Here, large individual differences between the nurses' vulnerability to background speech was observed. Whereas the number of observed unintended distractions ranges between 2 and 7 for N1-N4, 16 unintended distractions were logged during the analysis of N5.

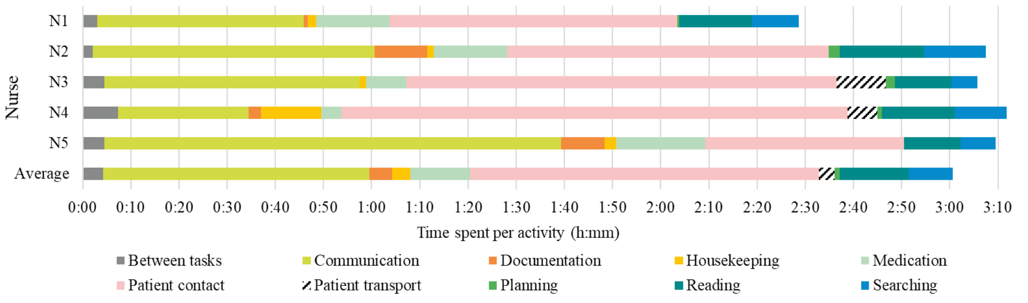

Figure 4-7 The amount of time spent on each activity for each observation.

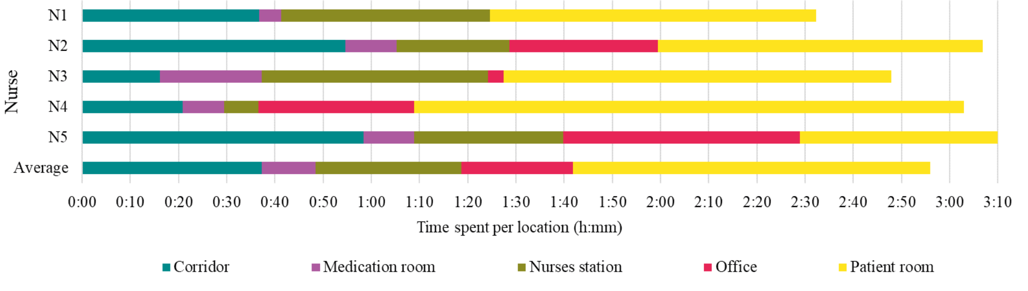

Figure 4-8 The amount of time spent in the most prominent locations for each observation.

Table 4-3 Percentage of time exposed to intelligible background speech during each activity and in the most prominent locations for each observation.

	Time exposed to background speech						
		N1	N2	N3	N4	N5	average
Activity	Between tasks	23,2%	0,0%	2,7%	5,8%	20,9%	10,5%*
	Communication	15,6%	13,1%	2,1%	18,2%	11,9%	12,2%
	Documentation	6,5%	20,0%	0,0%	1,9%	20,0%	9,7%*
	Housekeeping	7,8%	11,4%	49,3%	43,4%	9,2%	24,2%*
	Medication	16,8%	4,9%	0,0%	0,0%	11,9%	6,7%
	Patient contact	4,3%	5,1%	1,0%	4,4%	4,7%	3,9%
	Planning	0,0%	6,6%	8,0%	26,7%	0,0%	8,2%*
	Reading	71,1%	54,2%	40,7%	59,9%	86,0%	62,4%
	Searching	3,6%	11,9%	4,8%	13,9%	38,4%	14,5%
Location	Corridor	12,3%	7,5%	2,7%	9,0%	13,7%	9,0%
	Medication room	3,0%	0,0%	0,7%	1,0%	0,5%	1,0%
	Nurses' station	38,1%	12,5%	12,6%	7,1%	63,6%	26,8%
	Office	0,0%	46,9%	0,0%	41,2%	3,8%	18,4%
	Patient room	4,4%	5,6%	1,2%	8,5%	4,4%	4,7%

*Based on a total observation time of less than 25 minutes for that activity, and therefore considered not to be representative.

Table 4-4 The number of sound events, total and per hour, during each activity and in the most prominent locations for each observation.

		Sound events, total (per hour)					
		N1	N2	N3	N4	N5	average
Activity	Between tasks	3 (48)	4 (153)	8 (112)	5 (42)	5 (66)	5 (84,2)*
	Communication	27 (38)	65 (67)	37 (42)	6 (13)	33 (20)	33,6 (36)
	Documentation	0 (0)	9 (49)	0 (0)	6 (138)	17 (114)	6,4 (60,2)*
	Housekeeping	3 (106)	3 (137)	0 (0)	2 (10)	1 (25)	1,8 (55,6)*
	Medication	20 (79)	16 (64)	8 (58)	1 (14)	22 (71)	13,4 (57,2)
	Patient contact	88 (89)	91 (82)	19 (13)	45 (26)	36 (53)	55,8 (52,6)
	Planning	3 (450)	5 (131)	0 (0)	1 (60)	0 (0)	1,8 (128,2)*
	Reading	9 (36)	13 (45)	5 (26)	3 (12)	4 (21)	6,8 (28)
	Searching	8 (50)	8 (37)	8 (92)	6 (31)	3 (24)	6,6 (46,8)
Location	Corridor	47 (76,8)	90 (99)	18 (67,2)	15 (43,3)	62 (63,7)	46,4 (74,6)
	Medication room	0 (0)	3 (16,9)	14 (39,7)	2 (14)	1 (5,8)	4 (21,7)
	Nurses' station	19 (26,3)	10 (25,6)	30 (38,4)	4 (33,7)	17 (32,9)	16 (31,6)
	Office	0 (0)	21 (41)	4 (73,8)	7 (13)	5 (6,1)	7,4 (19,2)
	Patient room	91 (80,7)	90 (80,1)	19 (14,2)	44 (23,1)	32 (46,7)	55,2 (44,7)

*Based on a total observation time of less than 25 minutes for that activity, and therefore considered not to be representative.

Table 4-5 The number of pager calls during each activity and in the most prominent locations for each observation

		Pager calls					
		N1	N2	N3	N4	N5	average
Activity	Between tasks	1	0	0	3	2	1,2
	Communication	10	8	7	5	9	7,8
	Documentation	0	2	0	1	2	1
	Housekeeping	0	0	0	2	1	0,6
	Medication	1	1	1	2	1	1,2
	Patient contact	8	6	7	6	2	5,8
	Planning	0	0	1	0	0	0,2
	Reading	2	0	4	0	1	1,4
	Searching	3	4	2	1	1	2,2
Location	Corridor	10	12	5	8	5	8
	Medication room	1	0	2	3	2	1,6
	Nurses' station	5	2	8	1	2	3,6
	Office	0	2	0	2	2	1,2
	Patient room	11	6	6	7	2	6,4

Table 4-6 The number of intended (I) and unintended (U) distractions, total and per hour during each activity and in the most prominent locations for each nurse.

		Observed distractions, total (per hour)											
		N1		N2		N3		N4		N5		average	
		I	U	I	U	I	U	I	U	I	U	I	U
	Between tasks	2 (32)	0 (0)	0 (0)	0 (0)	1 (14)	0 (0)	2 (17)	0 (0)	5 (66)	1 (13)	2 (25,8)*	0,2 (2,6)*
	Communication	8 (11)	0 (0)	9 (9)	2 (2)	7 (8)	1 (1)	4 (9)	1 (2)	10 (6)	0 (0)	7,6 (8,6)	0,8 (1)
	Documentation	0 (0)	0 (0)	5 (27)	0 (0)	0 (0)	0 (0)	1 (23)	0 (0)	1 (7)	2 (13)	1,4 (11,4)*	0,4 (2,6)*
	Housekeeping	0 (0)	0 (0)	1 (46)	0 (0)	0 (0)	0 (0)	3 (14)	1 (5)	0 (0)	0(0)	0,8 (12)*	0,2 (1)*
Activity	Medication	5 (20)	4 (16)	1 (4)	1 (4)	1 (7)	0 (0)	1 (14)	0 (0)	0 (0)	2 (6)	1,6 (9)	1,4 (5,2)
	Patient contact	9 (9)	0 (0)	4 (4)	3 (3)	3 (2)	0 (0)	12 (7)	0 (0)	2 (3)	1 (1)	6 (5)	0,8 (0,8)
	Planning	0 (0)	(0)	0 (0)	(0)	0 (0)	(0)	1 (60)	(0)	0 (0)	(0)	0,2 (12)*	0 (0)*
	Reading	w5 (20)	1 (4)	4 (14)	0 (0)	5 (26)	1 (5)	6 (24)	0 (0)	3 (15)	7 (36)	4,6 (19,8)	1,8 (9)
	Searching	8 (50)	0 (0)	6 (28)	1 (5)	0 (0)	0 (0)	6 (31)	1 (5)	5 (41)	2 (16)	5 (30)	0,8 (5,2)
	Corridor	21 (35)	4 (7)	15 (16)	4 (4)	0 (0)	0 (0)	5 (15)	1 (3)	13 (13)	6 (6)	10,8 (15,8)	2,8 (3,8)
	Medication Room	1 (1)	0 (0)	1 (1)	0 (0)	4 (3)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	1,6 (1,2)	0 (0)
Location	Nurses' station	6 (8)	1 (1)	4 (10)	0 (0)	7 (9)	2 (3)	3 (25)	0 (0)	5 (10)	7 (14)	5 (12,4)	2 (3,6)
	Office	0 (0)	0 (0)	6 (12)	0 (0)	3 (56)	0 (0)	8 (15)	1 (2)	5 (6)	2 (2)	4,4 (17,8)	0,6 (0,8)
	Patient room	9 (8)	0 (0)	4 (4)	3 (3)	3 (2)	0 (0)	17 (9)	1 (1)	3 (4)	1 (1)	7,2 (5,4)	1 (1)

*Based on a total observation time of less than 25 minutes for that activity, and therefore considered not to be representative.

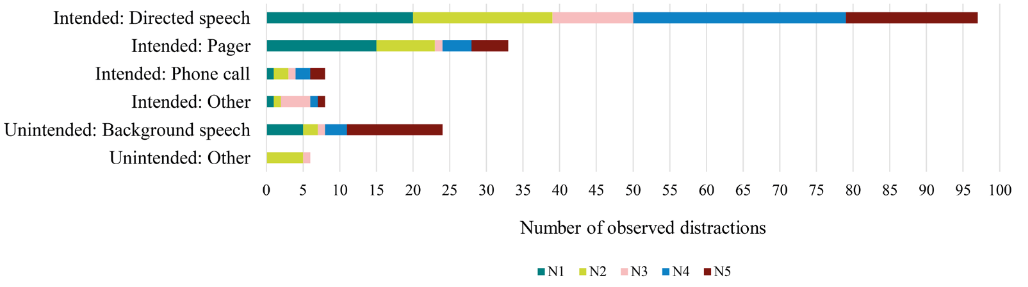

Figure 4-9 Sources and type of distraction per observation

4.3.3 Distractions in context

A contextual description of the observed distractions for one nurse (N1) is shown in Table 4-7. A short description of the context in which the distraction occurred is given as well as the current activity, location and the source of the distraction. Those distractions that were unintended (by the source of the distraction) are marked with an asterisk. Table 4-7 shows the contextual analysis of the 32 unintended distractions in the five timelines that were observed. Some of the distractions occurred within a short period of time and their descriptions are linked, these distractions are marked with a matching number of asterisks. For each distraction it was marked by the author whether the informational content, or the nurse's response to the distracting event could be regarded as useful in the professional, but not social context. Out of the 32 observed, unintended distractions, 10 (31%) were considered to be potentially useful.

Table 4-7 Overview of observed distractions from 1 observation in context.

activity	location	source	context
Reading	NS	DS	Colleague asks if chair is taken while N is reading
Comm.	NS	pager	Pager rings and N automatically looks to the room of an often calling patient.
Reading*	NS	BS	N is reading while colleagues talk about bandaging technique. N makes short comment but does not get involved in the conversation.
Reading	NS	DS	colleague leaves and says goodbye in general, N responds.
Searching	C	DS	A visitor asks for directions, N provides directions and moves on.
Med.	C	pager	Pager rings, N thinks aloud that it is no surprise that this patient calls.
Med.	C	pager	After pager continues, N instructs student to attend the call.
Med.	C	DS	A colleague informs N of leaving the ward with a patient going into surgery.
Med.*	C	BS	A colleague thinks out loud searching for student, N responds.
Med.*	C	BS	Colleague informs student of informing N, N responds.
Med.	C	DS	Student informs N that patient is on toilet.
P. contact	PR	pager	Pager rings, knows that patient is on toilet as a result from earlier distraction.
Med.*	C	BS	N overhears colleague asking patient if she wants to shower. When encountering that colleague in the ward 1 minute later, she informs about it.
Med.	C	DS	Colleague informs N of patient having pain.

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Med.	C	DS	Colleague informs N of doctor's visit order.
Med.	C	DS	Doctor says hello, wants to discuss patient. Mentions N should not be disturbed but asks for information anyway.
Med.*	C	BS	N looks up from her task in the direction of a personal background conversation (about a restaurant) between colleagues.
Searching	C	DS	A colleague asks N whether a doctor was still at the ward or had left already.
B.T.	NS	DS	A colleague asks N whether she needs a computer when entering the nurses' station.
Searching	C	DS	A patient asks N to close the curtains when N passes by the patient's room.
Searching	C	pager	N hears a pager, sees which patient is calling and decides to go later.
Searching	C	DS	Colleague utters something in passing, N responds.
P. contact	PR	phone	N answers phone, leads to second phone call.
P. contact	PR	pager	N looks at pager, no further action.
Searching	C	DS	N is walking to patient room when student asks about planning. N asks for more info and forms new intention based on info.
Searching	C	DS	N walks by patient room and patient starts to call, N responds that she will come.
Searching	C	pager	N hears pager and is annoyed since she already promised patient to come.
Searching	C	DS	Colleague asks N if she will go to patient who was calling.
P. contact	PR	pager	N looks at pager, no further action.
Searching	MK	DS	Colleague says good morning, N responds.
P. contact	PR	DS	Colleagues enter patient room while N is inside and say hello, wants to move on but N initiates conversation.

Note. Comm = Communication. Med. = Medication. P. Contact = Patient contact. B.T. = Between tasks. Doc. = Documentation. NS = Nurses' station. C= Corridor, PR = Patient room. MR = Medication room. DS = Directed speech. BS = Background speech. N = The observed nurse.

Table 4-8 Overview of observed, unintended distractions from all observations in context.

N	activity	location	source	context	Potentially useful
1	B.T.	C	BS	N is between tasks when she overhears a colleague talking to a patient about something that N has done earlier. N laughs and responds.	NO
2	Comm.	C	BS	N is listening to a doctor during their rounds. Two people meet and say "Hello, good morning" enthusiastically in the background. N looks up in the direction of that conversation.	NO
3	Comm.	C	O	N is talking to a doctor during their rounds. The door of the medication room closes loudly and N interrupts her sentence and says "Boom".	NO
4	Comm.	NS	O	N is teaching a student about procedures in the nurses' station. Due to a patient's limitations, not being able to reach the pager knob, there is a baby monitor in the room. N hears clicking heels through the baby monitor, recognizes them, laughs and says she know knows who is entering the ward.	NO

5	Comm.	Office	BS	N is discussing a patient with a colleague when two other colleagues say goodbye to each other. N responds by saying "sleep well" to the colleague who is leaving.	NO
6	Doc.	C	BS	N is entering information in the computer when she overhears two colleagues having a joyful conversation with a patient. N laughs.	NO
7	Doc.	C	BS	N is entering information in the computer when she overhears a colleague talking to a patient. The patient says something funny and N laughs.	NO
8	H.K.	PR	BS	N is making a patient's bed while that patient is in the bathroom. A doctor and a colleague are making rounds and talking to the patient. N has already indicated that she will listen in on their conversation to keep up to speed. Halfway their conversation N makes a comment on an earlier observation to make sure the doctor takes a look at it as well.	YES
9	Med.	C	BS	N just finished a short interruptive conversation with a colleague and shifts her focus back te the medication cart. Then, the colleague is thinking out loud wondering where her student went. Since N knows this, she responded and then continued with checking the medication. In this case, it helps the colleague to know where the student went, and delays the resumption of the original activity of N.	YES
10	Med.	C	BS	N is double-checking a patients status to make sure the correct medication is administered. At this moment she overhears colleague asking a patient (a fragment of intelligible speech) if she wants to shower. When encountering that colleague in the a few seconds later, she asks that colleague about it. While overhearing this fragment does provide information on what her colleagues are doing, it does divert attention from the medication task.	YES
11	Med.	C	BS	N is collecting medication for a patient and looks up from her task in the direction of a personal background conversation (about a restaurant) between colleagues. It shows that the background conversation diverted attention from the focal task.	NO
12	Med.	C	BS	N is collecting medication for a patient and overhears her colleague saying to her student: "N knows we are gone". N responds by confirming. It shows that the background conversation that contains N's name diverted attention from the focal task.	NO
13	Med.	C	O	N is thinking aloud when checking the medication for a patient. A patient cry interrupts her thoughts momentarily. After a pause of a few seconds N resumes her sentence. It shows that the cry from a patient room diverted attention from the focal task.	YES
14	Med.	C	BS	N is checking and collecting medication in the corridor when overhearing a loud conversation between a patient and a colleague. N thinks out loud about the hearing problems of that patient. It shows that the background conversation diverted attention from the focal task.	NO

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15	Med.	C	O	N is checking and collecting medication in the corridor when a colleague clears her throat. N laughs about it and gets involved in a short conversation. It shows that the background conversation diverted attention from the focal task and led to a longer interruption.	NO
16	P. Contact	PR	O	N is administering medication in a patients room when the breakfast trolley is moving closer and stopping near the patients room. N says “Have a nice meal, breakfast is coming!” The trolley noise provided this information.	YES
17	P. contact *	PR	O	N is helping a patient with ADL care when a loud cry from another room is audible. N thinks out loud wondering whether the cry is coming from one of her patients.	YES
18	P. contact *	PR	O	N is still helping a patient with ADL care when another loud cry from another room is audible. N now decides to interrupt her activity and check on the other patient. The other patient was almost lying on the floor and N had to help get him back into bed.	YES
19	P. contact *	PR	O	N is still helping a patient with ADL care, after returning from the previous interruption when another loud cry from another room is audible. N thinks out loud saying ‘I hope he stays put”.	YES
20	Reading	NS	BS	N is reading the EMR while colleagues talk about bandaging techniques. N overhears the conversation and makes short comment, but does not get involved in the conversation. It shows that the background conversation diverted attention from the focal task.	NO
21	Reading	NS	BS	N is reading the EMR in the morning when two other colleagues say goodbye to each other. N responds by saying “sleep well” to the colleague who is leaving.	NO
22	Reading	NS	BS	N is reading the EMR while colleagues have a personal conversation. N overhears the conversation and makes a short comment, but does not get involved in the conversation. It shows that the background conversation diverted attention from the focal task.	NO
23	Reading **	NS	BS	N is reading the EMR while colleagues have a personal conversation and laugh. N is reading out loud from the EMR, overhears the conversation and laughs as well, but does not get involved in the conversation. It shows that the background conversation diverted attention from the focal task.	NO
24	Reading **	NS	BS	N is reading the EMR while colleagues have a conversation about an organizational issue (lack of fitting clothes) and laugh. N is reading out loud from the EMR, overhears the conversation, laughs as well and makes a short comment. After this N gets back to reading the EMR. It shows that the background conversation diverted attention from the focal task.	NO

25	Reading **	NS	BS	N is still reading the EMR while colleagues have a conversation about an organizational issue (lack of fitting clothes) and laugh. N is reading out loud from the EMR, overhears the conversation, laughs as well and repeats part of a sentence from a colleague. After this, N gets back to reading the EMR. It shows that the background conversation diverted attention from the focal task.	NO
26	Reading **	NS	BS	N is reading the EMR while colleagues have a personal conversation and laugh. N is reading out loud from the EMR, overhears the conversation and laughs as well, but does not get involved in the conversation. It shows that the background conversation diverted attention from the focal task.	NO
27	Reading ***	NS	BS	N is reading the EMR while colleagues have a conversation about a patient (Not N's). N overhears the conversation and makes short comment, and then gets further involved in the conversation. It shows that the background conversation diverted attention from the focal task and led to a longer interruption.	NO
28	Reading ***	NS	BS	N just got back to reading the EMR after the interruptive conversation caused by the previous distraction. Colleagues now have a conversation about a training. N overhears the conversation and makes short comment, and then gets further involved in the conversation. It shows that the background conversation diverted attention from the focal task and led to a longer interruption.	NO
29	Searching	C	O	N is in the process of getting a pen and paper to write a note. When getting closer to a patient's room the hissing sound of a nebulizer becomes clearly audible and causes the nurse to enter the room and switch the nebulizer off. Here, the hissing sound provided a useful cue to perform an earlier intended action.	YES
30	Searching	C	BS	N has just collected some items for a patient in the medication room and is walking toward that patients' room. In the background an enthusiastic fragment of a conversation is audible and N looks up in the direction of that conversation.	NO
31	Searching****	O	BS	N is collecting items for a discharge package and overhears colleagues talking about error reports. N responds and shares her way of doing it.	YES
32	Searching ****	O	BS	N is collecting items for a discharge package and overhears colleagues talking about a patient situation and informs whether this is one of her patients.	YES

Note. N = nurse. Comm. = Communication. Med. = Medication. P. Contact = Patient contact. B.T. = Between tasks. Doc. = Documentation H.K. = Housekeeping.. NS = Nurses' station. C= Corridor, PR = Patient room. MR = Medication room. DS = Directed speech. BS = Background speech. N = The observed nurse.
*Distractions that occurred within a short period of time, descriptions are linked.

4

4.4 **Discussion**

In the current chapter, an exploration of auditory distraction in the field of nursing is presented. It was our aim to identify critical combinations of tasks and sound environments. To this end, a simultaneous analysis of activities and the sound environment they are performed in was conducted. Our specific focus was on visible distractions and the context they appeared in, the presence of intelligible background speech and potentially distracting sound events.

4.4.1 **The sound environment and distractions during different cognitive tasks**

Based on the observations, a clear distinction in sound environments can be made between the first twenty to thirty minutes of the shift and the remainder of the shift. The nurses were exposed to lengthy and full background conversations, dialogues, in the beginning of the shift while the sound environment during the remainder of the shift can be characterized by frequent notable sound events and fragments of intelligible speech. Both sound environments can be described as 'containing background speech' but could have different effects on the performance of different tasks. For example, in Keus van de Poll and Sörqvist (2016), halfalogues were found to have a less pronounced effect on writing speed than dialogues. Emberson et al. (2010) however, showed halfalogues to have a larger effect on the performance of a visual monitoring task and a reaction time task than both dialogues and monologues. Such outcomes emphasize the need for more in-depth analyses on the actual sound environment in various workplaces to replicate them in laboratory studies.

During the activities at the start of the shift, reading the EMR and receiving a verbal report, a cognitive task for the nurses is to take in vital information about patients and form intentions on what they have to monitor, assess and take care of for these patients during their shift. Our results show a high percentage of unintended distractions during the reading part of this task, which can be explained by the almost continuous presence of intelligible background speech. As can be seen from the overview of unintended distractions in Table 4-9, the context in which these distractions occurred cannot be seen as contributing to the overall job performance. While they might add to the social cohesion between colleagues, the potentially negative effects of distraction during this critical task are worth further investigation.

Reading is a semantic task, of which the performance has been shown to be negatively influenced by background speech (Halin, Marsh, Haga, Holmgren, & Sörqvist, 2014; Martin, Wogalter, & Forlano, 1988). Listening to speech (such as the verbal transfer) in the presence of intelligible background speech leads to an increased listening effort (Larsby, Hällgren, Lyxell, & Arlinger, 2005). The additional cognitive resources that are required to understand the relevant speech signal, can interfere with the processing of language and memory for what is being said (Peelle, 2018). Both reading the EMR and attending the verbal transfer, also include a planning and a memory component. To the best of our knowledge, no studies have been conducted that measure the effect of intelligible background speech, more specifically, dialogues on topics that could be interesting for the participant, on these complex tasks.

Another task that can have major consequences for a patient's health and safety is the collecting, checking and preparing of medication. In the observed ward, this task was performed in the relatively quiet (unless a colleague is there at the same time) medication room or in the more lively corridor. Checking and preparing medication is a focal task, and any mistake due to a distraction needs to be prevented. In many hospitals, including the one in which the current observations were performed, active measures are taken to reduce interruptions during medication rounds. Although there is only weak evidence on the efficacy of these measures (Raban & Westbrook, 2014), it might explain the relatively low number of observed distractions by directed speech as compared to another activity typically performed in the corridor: searching.

While involved with medication, seven unintended distractions were observed, all of which occurred in the corridor. As can be read from Table 4-9, five of these were caused by (fragments of) intelligible background speech originating from the ward environment. Given the limited time spent on this task during the first three hours of the shift, 12 minutes on average, and only partly in the corridor, this is an aspect to look into. Especially when considering the 'dark number' of distractions, those that were not observable. A recommendation for future research would be to study the effect of the typical ward sound environment, including fragments of intelligible speech and frequent notable sound events such as described in section 4.3.1, on the cognitive aspects involved with checking and preparing medication. An example of a representative experimental task can be found in Aarts et al. (2019). If the sound environment in the ward turns out to increase the risk of medication errors, interventions regarding the sound environment in the ward, or the location of medication handling should be investigated.

In the current study, patient contact was the broad term used for a multitude of activities performed while interacting with a patient. This includes administering medication (this means after preparation, collection and checking), checking an infusion, observing and caring for a wound, helping a patient in the shower and providing information. These are activities that require nursing skills and knowledge, but may not ask for the same level of concentration that is needed while reading or checking medication. It is important, though, that during these, sometimes routine, activities, no details or actions are forgotten. Forgetting to inspect a patient's skin that is affected by intertrigo (chafing), or to turn a patient are examples of missed care that can have serious consequences (Carthon, Lasater, Sloane, & Kutney-Lee, 2015; Kalisch et al., 2012). Distracting sound events and intelligible background speech could capture a nurses' attention and potentially cause the (momentarily) forgetting of an intended action. Whether reduction of speech intelligibility, for example between patient rooms and the ward, and the reduction of sound events that do not provide useful information (an example is the medication room door in the current ward, when it closes it can be heard throughout the ward) could be further explored.

To gain insight into the effect of the sound environment on these specific aspects of nursing care described above, a closer look at the processes involved in these tasks is required. The effect of the typical sound environments in the nurses' station and the ward corridor on the performance of these tasks could then be explored in dedicated laboratory studies. Our analysis of one specific task, forming and retrieving intentions for future care activities is presented in **Chapter 5** of this thesis.

4.4.2 The role of the sound environment during different cognitive tasks

Many of the potentially distracting sounds that were logged in this study can be viewed as a useful source of information. Several examples were found in the observed distractions, such as the noise of the breakfast trolleys, row 25 in Table 4-8, which may capture attention but also inform a nurse that breakfast is being served. The planning of next activities can be based on this information. More obvious examples are the patient cry, row 18 in Table 4-8, and the hissing sound of a nebulizer, row 29 in Table 4-8. Interviews with nurses on the information content of the sound environment could aid the further exploration of the role of sound.

The number of unintended distractions due to intelligible background speech is relatively low compared to the number of intended distractions due to directed speech. When colleagues see one another in the corridor, they often exchange valuable information that prevents them from having to plan a dedicated meeting. The importance of these casual encounters has been recognized (Carthey, 2008; Iedema, Long, Carroll, Van Marrewijk, & Yanow, 2010; Long, Iedema, & Lee, 2007), and could be taken into account in the design of hospital corridors (Verma, Alavi, & Lalanne, 2017). Our results show that, when nurses perform activities in the corridor and in patient rooms, a level of awareness is required that cannot be compared to the mindset that is used in most experimental settings.

The need for a high situational awareness and the level of concentration needed for focal tasks such as reading, checking medication or listening to a verbal report creates a conflict, and active measures such as marked quiet zones, or the yellow vests used in the observed ward, have not convincingly been proven to be helpful in reducing distractions and medication errors (Raban & Westbrook, 2014). Sharing the responsibility for patients in pairs, a system that is employed in the observed ward, could provide the opportunity to allow one person to perform activities that require a high level of concentration while the other monitors the ward. To facilitate this, dedicated rooms for focal tasks can be helpful. The concept of dedicated spaces for specific activities, sometimes referred to as 'activity-based design' is a present-day solution to acoustic problems in office and school environments (Braat-Eggen, 2020; Veldhoen, 2004).

The role of sound should not be ignored in experimental designs, especially when situational awareness is of key importance. We consider this to be the case for the more skills- and knowledge based tasks regarding patient care. Here, an experimental setting could be used that includes both relevant and irrelevant sounds for the task, to explore the effect of measures aimed at the reduction of only irrelevant sounds.

4.5 **Limitations**

Although this study led to valuable insights on the combinations of task and sound in a nursing ward, several limitations have to be acknowledged.

First, in the interpretation of results we have to take into account that the observations were performed in one ward. The hospital under study was built in 2013, and considerable attention was paid to creating healing environments. The ward was acoustically treated and consists of only single-patient rooms. While this makes our results representative for current day practice, important issues that could still occur in older buildings may have been overlooked.

A second limitation regards the validity of the data analysis. Due to the privacy sensitive nature of the data, the analysis was conducted by the author only. Intra-person variation of the analysis could therefore not be conducted. To counter this limitation, the content of distractions for one observation were included.

Third, although carefully considered, the method of data collection using the Think Aloud method inevitably brings about a set of limitations. The method was chosen for two main reasons. First the absence of creating a predetermined focus on distractions (which is a distraction in itself) amongst the participants, and second, the possibility to simultaneously collect data on the nurses' task execution which will be analyzed in Chapter 5. This method, however, has left us dealing with an unknown 'dark number' of distractions. Distractions that do not fully take away the attention from the current task, or are not verbalized, are not observable. In this study, we have assumed the number of visible distractions to be a representative indication of both the distraction potential of the sound environment and the distraction sensitivity of a task. Another limitation linked to using TA is the varying competence of the nurses in verbalizing thoughts, which may explain the difference in observed distractions between individuals. Although the nurses received clear instructions regarding TA, both one day prior to the observation and at the start of the observation, they did not receive any training.

A final limitation that has to be mentioned is the fact that we only took into account distractions that were clearly auditory. All sensory modalities can cause distraction and in a dynamic workplace such as a hospital ward the combination of senses are an important aspect to consider in future studies.

4.6 Conclusion

The results provide insight in the type of activities that are conducted during the first hours of a typical morning shift, the corresponding auditory environment and their interaction. Two critical focal activities were identified, the planning of care activities while reading the EMR or receiving verbal transfer, and medication handling. Planning care in the nurses' station while being exposed to continuous background speech is considered to be a critical combination of tasks and sound environment. A second critical combination is the sound environment in the corridor while medication handling. Forgetting intentions for care activities is the third risk that was identified, here, both the sound environment while forming intentions and the sound environment at the intended moment of retrieval could play a role.

The role of sound was explored by analyzing the informational content of observed distractions. Reading the EMR, listening to the verbal transfer and administering medication are focal tasks which require a level of focus that conflicts with the situational awareness needed to act on sound events containing relevant information. It is suggested to further explore both the effect of the sound environment these tasks are performed in and the possibility to create specific places to perform focal tasks without being disturbed. The information gathered through this observation can help to understand where distractions originate and whether they are necessary for the care of patients or should be eliminated.

Taking into account the role of sound in an experimental design is especially important for those tasks that are inevitably linked with a high level of situational awareness.

5

Planning and executing prospective memory tasks

5 Planning and executing prospective memory tasks

Missed nursing care can affect patient safety, patient satisfaction and staff satisfaction. The extent to which forgetting to execute intended care activities contributes to missed nursing care is addressed in this chapter. Remembering to execute intended activities requires prospective memory, a concept that has been relatively unexplored in the context of nursing. An observation study combined with questionnaires was conducted in a nursing ward to log the forming and retrieving of prospective memory tasks. The results indicate that, according to nurses' self-report, over 40% of delayed and omitted nursing activities were due to prospective memory failures. This implies that improving nurses' PM performance has the potential to decrease missed nursing care.

5.1 Introduction

An important cognitive aspect of the work of a nurse, working in a hospital ward, is to plan, prioritize and execute activities in order to deliver the required care for their patients. Failing to execute an intended activity at the right time (a delay), or not executing it at all, leads to an error of omission, also described as ‘missed nursing care’ (Kalisch, Landstrom, & Hinshaw, 2009). Errors of omission have received an increasing amount of research attention in the past 20 years (Jones, T. L. et al., 2015) and have the potential to influence patient outcomes (Ball et al., 2018; Carthon et al., 2015; Kalisch et al., 2012; Nelson & Flynn, 2015), patient satisfaction (Lake et al., 2016) and job satisfaction (Kalisch, Tschannen, & Lee, 2011a; Tschannen et al., 2010).

Examples of missed care that have been linked to patient falls are ambulation, patient assessments in each shift, focused reassessment, response to patient calls and assistance with toileting (Kalisch et al., 2012). In a nursing home setting, failure to administer medication on time and failure to predict adequate patient surveillance were significantly associated with urinary tract infections (Nelson & Flynn, 2015)

The Missed Nursing Care Model developed by Kalisch (2009), describes a nurse’s internal processes regarding missed care as the choice to complete, delay or omit items of patient care. Four factors are identified to influence this decision, team norms, decision-making processes, internal values and beliefs and habits. The main body of research addressing these factors focuses on organizational issues, such as workload (Ball, Murrells, Rafferty, Morrow, & Griffiths, 2014; Orique, Patty, & Woods, 2016; Tubbs-Cooley, Mara, Carle, Mark, & Pickler, 2019), staffing levels (Dabney & Kalisch, 2015; Kalisch, Tschannen, & Lee, 2011b; Kalisch et al., 2012) and the work environment (Carthon et al., 2015; Kim, K., Yoo, & Seo, 2018; Smith, J. G., Morin, Wallace, & Lake, 2018; Winsett et al., 2016). In a comprehensive review, time scarcity was indicated as the primary driver of missed care (Jones, T. L. et al., 2015) .

In the current chapter, we address missed care from a different point of view, focusing on the possibility of omissions occurring not by choice, but due to forgetting. Remembering to carry out activities at the right time requires prospective memory (PM) which describes our ability to remember to perform an activity in the future, sometime after we initially formed the intention to perform that activity (McDaniel & Einstein, 2007). Typical examples of PM tasks in the context of nursing are a drug that has to be administered during a specific time frame, information that has to be passed on to a doctor, or following up on a patients inquiry. Whenever a mental note is made to remember to do something later on in the shift, this adds to the PM load (Meier & Zimmermann, 2015).

In the main body of research on PM, PM tasks are referred to as either event-based or time-based (McDaniel & Einstein, 2007). An event-based task needs to be recalled when a certain event happens, like remembering to pass on particular information to a doctor during medical rounds. A time-based task must be retrieved at a specific time or after a specific amount of time has passed. A third type of PM task, activity-based PM tasks, is defined by some as tasks that are intended to be completed after the successful completion of another activity (Brewer et al., 2011; Kvavilashvili & Ellis, 1996). A completely different classification of PM tasks originates from the field of aviation. Dismukes et al. (Dismukes & Nowinski, 2007) distinguish episodic tasks, habitual tasks, atypical actions substituted for habitual actions, interrupted tasks and interleaving tasks. Tasks that have to be performed at a specific time that do not habitually have to be performed at that time are called episodic tasks. Habitual tasks are tasks that are performed very often in a well-known sequence, and it can be argued whether these are really PM tasks (Dismukes, 2008). Tasks that require a deviation from a routine sequence of activities are described as atypical actions substituted for habitual actions. Tasks that have to be resumed after an interruption are interrupted tasks, and interleaving tasks are described in the context of multitasking and prolonged attention for one task may not cause another to fail. All of the task types distinguished by Dismukes et al. can be time-based, event-based or activity based.

5.1.1 **Prospective memory in nursing**

Although the importance of PM in healthcare is recognized (Dieckmann, Reddersen, Wehner, & Rall, 2006; Dismukes, 2012; Fink et al., 2009; Fink et al., 2010; Grundgeiger, Liu, Sanderson, Jenkins, & Leane, 2008), literature on the role of PM in nursing is scarce. Only a handful of studies were found that were performed in a range of healthcare settings. Grundgeiger et al. (2009) executed a field study in an ICU and classified observed PM tasks to look into how environmental aspects can contribute to remembering the different types of PM tasks. In another study by the same authors, a positive effect of visual cues on prospective remembering was measured in an ICU simulator. Due to the limited amount of studies on this topic, the role of PM for nurses in a hospital ward is unclear. Knowledge about the number and type of PM tasks that have to be remembered over a period of time and those that are forgotten, how and when intentions are formed and whether planning aids are used, as well as the factors influencing PM performance is lacking.

Choosing whether or not to execute a task, a key factor in missed nursing care, is dependent on the perceived relative importance of that task. Laboratory studies on PM have also identified task importance as a predictor of PM performance (Kliegel et al., 2001; Kliegel, Martin, McDaniel, & Einstein, 2004). Therefore, it is expected that the priority that nurses attach to intended tasks influences the odds of that task being performed in time. Not only by choice, but also subconsciously.

5.1.2 **Aim of the study**

The current chapter aims to explore the role of PM in missed nursing care, by measuring the number and type of PM activities that a nurse has to remember, how and when they are planned, when and whether they are executed. For each delay and omission it will be determined whether they are caused by PM failures. Additionally, the role of priority and planning aids will be explored.

5.2 Method

5.2.1 **Data collection**

An extensive description of the study design and the hospital in which data collection took place is can be found in **Chapter 3** (section 3.3). The data that was used in the current analyses are the two observation logs from researchers A and B on the twelve observations, the copies of any notes made by the nurses during the observations, the questionnaires on self-reported PM execution and perceived priority and the audio recordings that were made during the observations (see Figure 3-5).

Table 5-1 Overview of variables derived from the available data. Log A is the observation log created by researcher A. Log B is the observation log of researcher B.

Data set	Variable
Log A aided by log B and audio	Content of logged intentions
Log A aided by log B	Time each intention was formed
Log A	Time each intention was executed
Log A + copies of notes made by the nurses.	Internal cue
Questionnaire	Execution according to the nurse
Questionnaire	Nurses' rating of priority

5.2.2 **Data analysis**

From the information in observation log A, supplemented by the information in observation log B, a list of intended activities was compiled for each nurse (N = 12). For each intention a set of basic variables was built as described in Table 5-1. The times at which intentions were formed and executed were derived from the detailed log of the nurses' activities and verbalized thoughts in the observation sheet created by researcher A. The audio recordings and the observation sheet created by researcher B were used to verify the logged intentions. To calculate the number of 'active' intentions, the PM load, at a specific time (Tx), the cumulative number of performed PM activities was deducted from the cumulative number of formed intentions.

PMload at Tx = Sum of logged intentions at Tx – Sum of executed intentions at Tx.

If a nurse created a reminder for a specific intention, by making a note on a piece of paper for example, or intentionally leaving something in sight to make sure it was seen later, this was logged as an internal cue. Because the observations stopped at around 10:00 AM and the questions regarding PM execution were asked during the nurses' lunch break a few hours later, only their answers on PM execution were used to calculate PM outcomes. To be able to compare the ratings of priority by the different nurses for the intentions, standardized scores were calculated based on each nurse's average rating of priority and standard deviation.

5.2.2.1 ***Classification of PM tasks***

After retrieving the basic variables from the data, a content analysis was performed for each intended activity. As described in **Chapter 3** (section 3.1), any time a nurse verbalized the intention of performing an activity during the shift, that was not immediately followed by execution was considered a PM intention. As a result, tasks that were performed for each patient every shift were also considered PM tasks even though their retrieval may be less dependent on prospective memory as they are part of a daily routine. These tasks can be considered 'habitual' according the classification of Dismukes & Nowinski (2007). Furthermore, according to some theorists, a PM task can only be considered a PM task, if a daily routine or activity needs to be interrupted in order to perform the PM task (McDaniel & Einstein, 2007).

In our logging of PM tasks, tasks that can be executed after finishing the current task, or after finishing several other tasks, were also logged as PM tasks. This is in line with Kvavilashvili & Ellis (1996) who distinguish activity-based PM tasks that are to be performed prior to or after a specific activity. Based on the above, the pragmatic decision was made to classify all intended activities as either time-based, event-based or activity-based. In our interpretation of event-based and activity-based tasks, all events were considered to be external and therefore not influenced by the nurse. A colleague completing a task was therefore considered to be an event. An activity was considered to be an activity conducted by the observed nurse.

A second classification of intentions was applied according to the PM types defined by Dismukes and Nowinski (2007). In general, the nurses' morning routine consisted of reading and handover, a medication round, ADL care including wound care, and a visiting round. Any intentions for, or part of, these routine activities were labeled as 'routine'. Another example of a routine task is writing the name of the nurses on the patients' whiteboards.

To gain insight in the possible effects of PM failures, the researchers determined for all delays and omissions whether it had the potential to affect patient safety or patient satisfaction. This was based on researcher A's experience as a nurse. An example of a task for which a delay or omission that could potentially affect patient safety is measuring a patient's blood sugar level. This has to be performed before breakfast. Any delay or omission potentially affecting patient safety was considered to potentially affect patient satisfaction as well. An example of a delay or omission that could potentially affect patient satisfaction is not switching off a nebulizer after ten minutes as promised. Such a delay or omission could make a patient feel neglected. It was not registered whether possible effects actually occurred.

5.2.3 **Statistical Analyses**

SPSS 25 was used to analyze the data. Chi-square tests of homogeneity were used to discover possible differences in the retrieval of adjusted PM intentions between the different task types and to explore the effect of cues. To gain insight into the role of priority, a Kruskal-Wallis test was used. Statistical significance was assumed at $\alpha = 0.05$.

5.3 **Results**

Twelve nurses, of which eleven females, participated in the study. Their average age was 26.2 (S.D. = 3.0) and their average years of working experience was 4.7 (S.D. = 3.1). Observations were conducted in two surgical (one orthopedic ward and one trauma/gynecology ward) wards of the same hospital. A total of 37.5 observation hours were analyzed during which 978 intentions were logged. The number of internal cues created by the individual nurses ranged from 6 to 43.

5.3.1 **Task types**

As described in paragraph 5.2.2, PM intentions were classified as either time-based, event-based or activity-based. While for some intentions this distinction was very clear, it was harder to make in other cases. For example, the intention to administer antibiotics to a patient at 08:00 is an obvious time-based intention, but the intention to administer mediation to a patient as part of the medication round is less clear. In both wards, the medication round was one of the first activities nurses performed, starting at around 07:30 AM. As such, it could be considered a time-based intention. In the current analysis, however, this intention was labeled as an activity-based task, because the medication round was typically performed at the start of the shift, after reading the electronic medical records (EMR) and the verbal transfer. Another example is the intention to help a patient to practice walking with crutches. This intention is not linked to either an event or a specific time but will be executed by the nurse at some point during the shift. A fourth category of intentions was therefore created, labeled as free PM intentions. Other intentions that were labeled as free PM intentions were those that remained active during the shift. For example, to keep a direct colleague informed every now and then, or to monitor a patient's pain throughout the shift. Table 5-2 presents the distribution of the PM types in the two categorizations.

Table 5-2 Distribution of the different PM types

PM type	PM type				Total
	Time-based	Event-based	Activity-based	Free	
Episodic	132	175	156	300	763 (78.0%)
Habitual	8	47	132	2	189 (19.3%)
Atypical	0	4	2	1	7 (0.7%)
Interrupted	2	0	6	11	19 (1.9%
Interleave	0	0	0	0	0 (0.0 %)
Total	142 (14.5%)	226 (23.1%)	296 (30.3%)	314 (32.1%)	978

An adjusted number of 634 intentions was calculated by removing the habitual PM tasks, the activities that were performed within 3 minutes of forming the intention, activities that were originally planned to be executed after the nurses' lunch breaks and any other tasks that were omitted because they became redundant.

From the 634 adjusted PM intentions, 119 (18.8%) were considered to be time-based, 135 (21.3 %) intentions were labeled as event-based, 123 (19.4%) were labeled as activity-based and 257 (40.5%) intentions were labeled as free. Due to the limited number of interrupted and atypical intentions, no further analysis on the differences between these categories was performed.

5.3.2 Planning and task load

Figure 5-1 shows the adjusted PM load during each shift for all the nurses based on a one-minute resolution. The maximum number of intentions that a nurse had to remember at a certain moment in time ranges from 17 to 41 across nurses. The time-weighted average across nurses was 20.4 intentions. The figure clearly shows that the first 15-30 minutes in each nurse's shift can be characterized by a steep rise in PM load. The activities that were being performed during these sharp increases of PM load are the verbal change of shift report and reading the EMR. After these activities, the participants were asked by the researchers to recall what they had planned for that day. Following the change of shift transfer, a period of reading and the short interaction with the researchers, a certain level of PM load was more or less maintained as new intentions are formed while PM tasks are being performed. Steep rises of the PM load halfway the observation period were typically due to an information exchange between the nurse and a colleague who was responsible for the same set of patients.

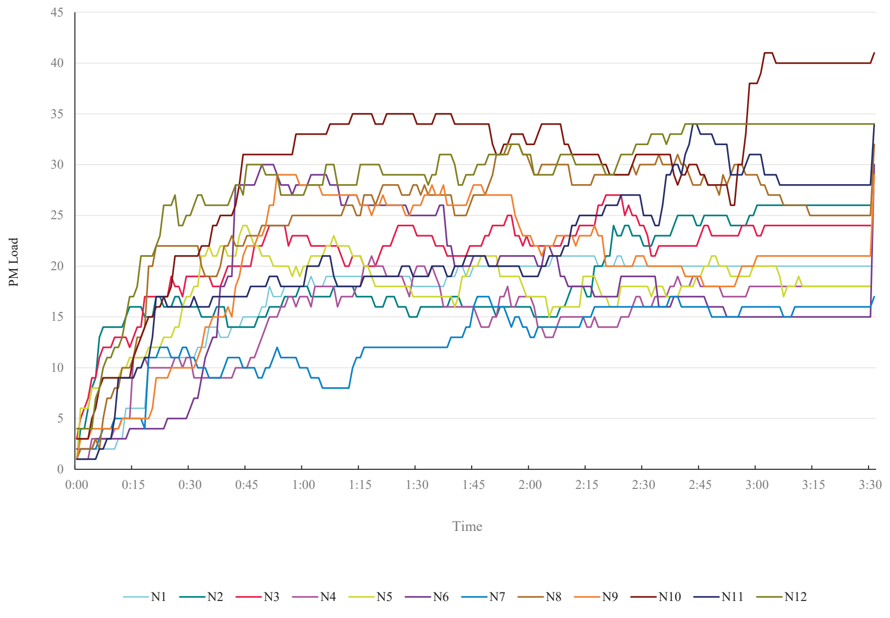

Figure 5-1 A timeline of the adjusted PM load for the individual nurses. Each colored line represents one nurse.

5.3.3 Execution of prospective memory intentions

Out of the 978 intentions that were logged, 724 (74.2%) were executed in time, 73 (7.5%) were delayed and 175 (17.9%) were omitted. The question regarding task execution was not answered for six intentions, leading to missing data for these items. Based on the nurses' own judgement, 30.2% of these delays and omissions occurred due to PM failures. Taking into account only the number of adjusted intentions, 473 (74.7%) were executed in time, 57 (9.0%) were delayed and 102 (16.2%) were omitted. Based on the nurses' judgement, 30 delays and 39 omissions were the result of a PM failure, accounting for 43.4 % of delays and omissions. An overview of the PM task execution, taking into account all intentions for each nurse is presented in Table 5-3.

Table 5-3 Overview of PM task execution for the individual nurses.

N	PM execution					
	In time	Delays		Omissions		Total
		Deliberate	PM failure	Deliberate	PM failure	
N1	44	7	6	4	3	64
N2	42	4	5	8	5	64
N3	76	5	3	9	3	96
N4	45	3	1	11	7	67
N5	60	3	3	12	0	78
N6	57	1	3	8	1	70
N7	56	5	1	0	2	64
N8	82	2	1	13	3	101
N9	52	4	2	14	7	79
N10	79	1	1	23	5	109
N11	59	4	6	17	4	90
N12	72	1	1	14	2	90

5.3.3.1 *Effect of task type*

From the 185 habitual intentions that were logged, 169 (91.4%) were completed in time according to the nurses' self-report. Out of the 762 episodic intentions, 534 (73.8%) were completed in time.

To discover possible differences in the retrieval of adjusted PM intentions between time-based, event-based, activity-based and free tasks, a chi-square test of homogeneity was used. A significant difference for PM execution based on task type was found, $\chi^2(8) = 31.133$, p = 0.002. Observed frequencies and percentages of task types in each category of PM execution are presented in Table 5-4. Post hoc comparisons revealed that in-time retrievals occurred significantly more often for activity-based tasks compared to event-based and free tasks (*n* = 85.2% versus *n* = 0.9% and *n* = 70.4%). Furthermore, there was a statistically significant difference in the proportion of free tasks compared to activity-based tasks that were omitted as the result of a PM failure (*n* = 9.3% versus *n* = 1.6%). No other pairwise comparisons were statistically significant, but as can be seen in Table 5-4, omissions due to a PM failure seem to occur slightly less often in time-based compared to event-based and free tasks. Deliberate omissions seem to occur slightly more often in free PM tasks and event-based tasks, compared to time-based and activity-based tasks.

Table 5-4 Cross-tabulation of PM execution (adjusted PM intentions) according to the nurses and type of PM intention.

PM execution		PM type				Total
		Time based	Event-based	Activity-based	Free	
In time		93 (78.2%)[a.b.c]	95 (70.9%)[c]	104 (85.2%)[b]	181 (70.4%)[a.c]	473
Delay	Deliberate	6 (5.0 %)[a]	6 (6.0%)[a]	4 (3.3%)[a]	9 (3.5 %)[a]	27
	PM failure	11 (9.2%)[a]	6 (4.5%)[a]	5 (4.1%)[a]	8 (3.1%)[a]	30
Omission	Deliberate	6 (5.0%)[a]	15 (11.2%)[a]	7 (5.7%)[a]	35 (13.6%)[a]	63
	PM failure	3 (2.5%)[a.b]	10 (7.5%)[a.b]	2 (1.6%)[b]	24 (9.3%)[a]	39

Note. Superscripts indicate subsets of PM type categories for which task execution does not significantly differ from each other. Bonferroni corrections are applied.

5.3.3.2 *Effect of internal cues*

The observed nurses made frequent use of written reminders to execute tasks. Only on a few occasions the nurse left something intentionally in sight to be able to act upon it later. The percentage of intentions for which cues were created varied from 12.2 -57.6% between the individual nurses.

In total, 222 cues were created, of which 209 were created for episodic PM intentions, 7 for habitual intentions and 6 for interrupted tasks. A large difference was also found in the number of cues that was created between time-based and free PM intentions compared to event-based and activity-based intentions, (n = 34.5% and n = 34.4% versus n = 16.8% and n = 9.1%). A chi-square test of homogeneity revealed this difference to be significant, $\chi^2(3) = 71.321$, $p < 0.001$.

To discover possible differences in the retrieval of adjusted PM intentions as a result of internal cues, a chi-square test of homogeneity was used. No significant differences for PM execution were found as a result of internal cues, $\chi^2(4) = 6.941$, $p = 0.139$. Observed frequencies and percentages of internal cues that were used for each category of PM execution are presented in Table 5-5. Intentions for which the nurse created a reminder led to deliberate omissions slightly more often than those for which no reminders were created.

Table 5-5 Cross-tabulation of PM execution (adjusted PM intentions) according the nurses and the use of internal cues.

PM execution		Internal cue		
		No cue	Cue	Total
In time		343 (75.7%)	130 (72.6%)	473
Delay	Deliberate	19 (4.2%)	8 (4.5%)	27
	PM failure	24 (5.3%)	6 (3.4%)	30
Omission	Deliberate	37 (8.2%)	26(14.5%)	63
	PM failure	30 (6.6%)	9 (5.0%)	39

5.3.3.3 *The role of priority*

To be able to compare priority ratings for the PM intentions across nurses, standardized ratings of priority were calculated based on each nurse's mean rating of priority. Figure 5-2 shows the standardized priority ratings for each category of PM execution.

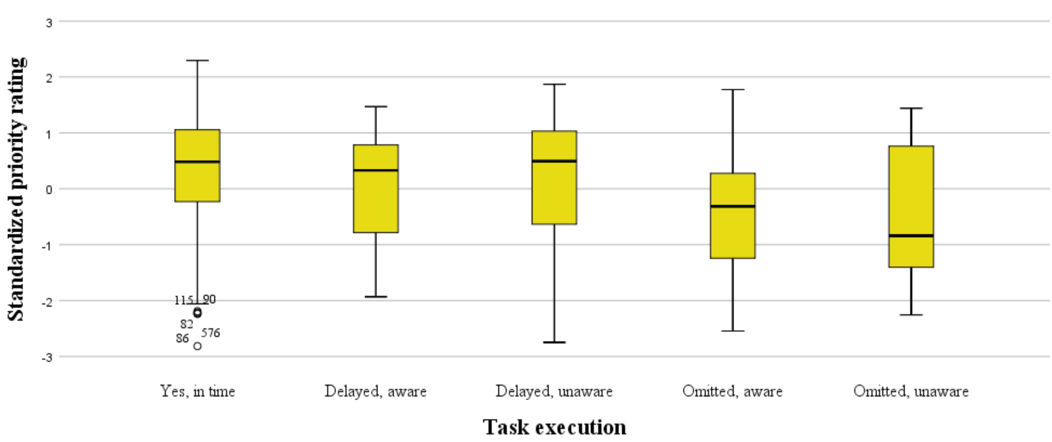

Figure 5-2 Boxplot showing the standardized priority ratings for the different types of PM execution

A Kruskal-Wallis test taking into account the adjusted PM intentions, showed a statistically significant difference in standardized ratings of priority between the different PM outcomes, $H(4) = 46.269$, $p < 0.001$. Pairwise comparisons, using adjusted p-values, showed that there was a significant difference in priority ratings between intentions that were executed in time and intentions that were deliberately omitted ($p < 0.001$, r = 0.242), and a significant difference in priority ratings between intentions that were executed in time and intentions that were omitted due to a PM failure ($p < 0.001$ r = 0.185). No other significant differences in priority ratings between the different PM outcomes were found.

Figure 5-3 shows the standardized priority ratings for the different categories of PM tasks. A Kruskal-Wallis test taking into account the adjusted PM intentions showed a statistically significant difference in standardized ratings of priority between the different PM outcomes, $H(3) = 12.932$, $p = 0.005$. Pairwise comparisons, using adjusted p-values, showed that there was a significant difference in priority ratings between event-based PM intentions and free PM intentions ($p = 0.01$, r = 0.158). No other significant differences in priority ratings between the different PM outcomes were found.

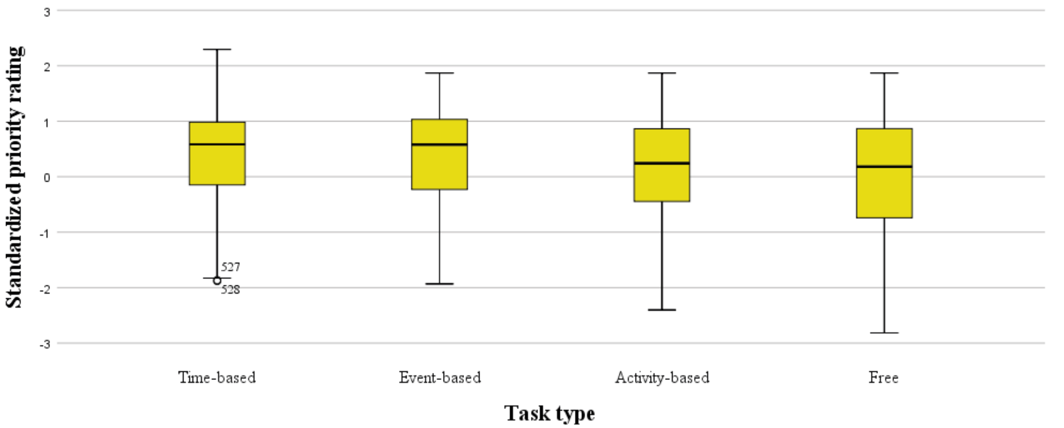

Figure 5-3 Boxplot showing the standardized priority ratings for the different types of PM tasks.

5.3.4 Possible consequences

For each delay and omission, it was determined whether it could potentially have an effect on patient safety or patient satisfaction. The results of this analysis are visualized in Figure 5-4. Out of the 57 delays, 9 (15%) were considered by the researchers to potentially affect patient safety and 23 (40%) were considered to potentially affect patient satisfaction. Out of the 102 omissions, 30 (29%) were judged to potentially affect patient safety, and 34 (33%) were judged to potentially affect patient satisfaction. PM failures were judged to possibly affect patient safety in 27 (42%) out of 69 cases, and to affect patient satisfaction in 22 (31%) out of 69 cases.

Examples of PM failures that were considered to possibly affect patient safety were forgetting to weigh a patient, forgetting to make sure a patient would take the administered medication after ADL care and forgetting to double check (measure again) a patient's blood pressure. Examples of PM failures that were considered to possibly affect patient satisfaction were forgetting to help a patient inserting a hearing aid, forgetting to arrange a patient's discharge on time (delay) and forgetting to shut down a nebulizer 15 minutes after installing it (delay).

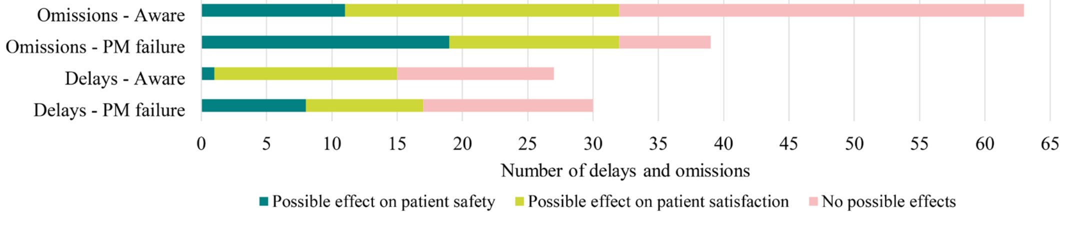

Figure 5-4 Possible consequences of delays and omissions.

5.4 **Discussion**

In this exploration on the role of PM in nursing, the forming of intentions was measured by observation and the execution of these intentions was measured by nurses' self-report. It was our expectation that PM performance of nurses may be a predictor of missed care.

During the observations, an adjusted number of 634 PM intentions were logged, of which, according to the nurses' self-report, 159 were either delayed or omitted. PM failures were the cause of 43.4% of these delays and omissions which indicates an important role of PM in missed nursing care. As could be expected, the routine, or habitual, intentions that were logged during the observations turned out to have the lowest rate of delays and omissions. Based on an experienced nurse's judgement, 73% of the PM failures could potentially affect patient safety or patient satisfaction.

5.4.1 **Addressing PM failures**

The number of studies directly comparing retrieval of event-based and time-based PM tasks is limited and suggest that performance differences across these tasks are dependent on the type of event-based task that is tested (Conte & McBride, 2018). In our reading of the literature, no studies were identified in which performance on activity-based PM tasks was directly compared to the other categories. In a nursing setting, knowledge on the sensitivity to PM failure for time-, event-, or activity-based tasks can help to address such failures. In our study sample, delays as a result of a PM failure occurred more often for time-based tasks compared to the other types, but this was not the case for omissions. In our analysis of the data, we defined a fourth type of task, the 'free' task. These tasks were intended to be performed during the observed part of the nurses' shifts, but there was no specific event, activity or timeframe that could be regarded as 'the window of opportunity'. The highest rate of omissions was found for these tasks. A possible explanation for these results could be the accurateness of this window of opportunity, which is very obvious for time- and event-based tasks, becomes a bit more vague in the case of an activity-based task and is very broad in the case of a free task. Theoretically, a task cannot be executed too late if there is no specific timeframe in which a task is to be performed. This is in line with evidence suggesting that forming 'implementation intentions', which means specifying when, where and how the intention should be performed in advance, increases goal achievement (Gollwitzer & Sheeran, 2006). This could be reflected in the (only slightly and non-significant) higher rate of delays in time- and also event-based tasks as compared to free and activity-based tasks. In the context of nursing, creating the habit of forming implementation intentions when planning care could reduce errors of omission.

In the interpretation of the results described above, though, we have to take into consideration the difference between self-reported priority for the different types of PM tasks as well. The results indicate a significantly lower self-reported priority for free PM tasks, and the self-reported priority for intended tasks was found to be an important factor in the occurrence of PM failures. This is in line with findings from several laboratories exploring the role of priority (or task importance) in the monitoring and retrieval mechanisms that are involved with prospective remembering (Kliegel et al., 2001; Kliegel et al., 2004). As could be expected, a lower priority was also associated with the tasks that were deliberately delayed and omitted. Therefore, the effect of task type on PM execution must be interpreted with caution. The effect of self-reported priority on self-reported task execution also implicates the importance of nurses' prioritization skills as well as their ability to assess task importance.

In the current study, nurses made frequent use of written notes to remind them of their intended tasks. They kept a piece of paper to which they referred to as their 'external memory' in their pockets at all times. In this light, our findings, suggesting that cues had no effect on PM performance, are unexpected and in contrast with a study by Grundgeiger et al. who investigated the effect of visual cues on prospective memory in a different healthcare sector, the ICU (Grundgeiger et al., 2013). The high number of deliberate omissions for PM tasks with a cue compared to those without is noteworthy. This could be because the cue constantly reminds the nurse of the to be performed task, making it impossible to become a PM failure. Further research is required to gain insight in the effectiveness of notes and other reminders on PM performance in a clinical setting. With regard to cues, the external environment, being colleagues, patients themselves or equipment should not be overlooked.

A valuable exploration of such environmental cues, referred to as distributed prospective memory, was performed by Grundgeiger et al. (2009). In this work, Grundgeiger builds on the 'distributed cognition' view (Hutchins & Klausen, 1996) that regards the performance of a system as a whole rather than the performance of an individual within that system. In terms of PM and patient outcomes, the performance of a system is what would be most relevant. Whether a nurse would spontaneously retrieve the intention to administer medication, or was prompted by a colleague, a set alarm or another designed, perhaps less unobtrusive reminder, does not affect the outcome.

Studies on the effect of PM load on PM performance have yielded inconsistent results (Meier & Zimmermann, 2015). The current data is not suitable to explore this relation, but does provide a realistic insight in the PM load in a natural setting. This can serve as input for future experimental designs. The average PM load of the participants in the current study (at Tx, after reading and the change of shift transfer) is never lower than 22. This is considerably higher than in the typical PM tasks that are used in laboratory experiments on PM performance. A typical paradigm for studying PM, for example, comprises asking subjects to remember to respond (hit a key, ring a bell) whenever they see a particular target item (PM cue) in the context of an ongoing task (PM load = 1) (Einstein et al., 2005). One example was found in the field of nursing that approaches this task load. Grundgeiger et al. (2013) used 40-minute scenarios in which 8 PM tasks had to be performed in an intensive care simulator to investigate the effect of visual cues on PM performance.

Given the high percentage (73%) of PM failures that were judged to potentially affect either patient safety or satisfaction, addressing PM performance in nursing care is worthy of further investigation. One way to address PM failures is to train nurses in using their PM. Studies on the efficacy of PM training generally address older adults and people with brain injuries, but results are promising (Fleming, Shum, Strong, & Lightbody, 2005; Waldum, Dufault, & McDaniel, 2016). Further research on PM in nursing, with a specific focus on the development of training strategies is suggested. Creating the habit of forming 'implementation intentions' could play a role here.

5.4.2 **Measuring intentions and task execution**

An important methodological aspect of the current study was how intentions for future activities were captured. Two other studies were identified that captured PM intentions in a hospital ward setting using video recordings (Grundgeiger et al., 2009) and observations during which the observer derived intentions, here described as 'patient care activities and priorities' from querying an observed nurse at the end of initial patient morning rounds and by analyzing the early morning change-of-shift report (Potter et al., 2005). In our data collection the Think Aloud method was used to capture PM intentions, aiming to reduce the risk of missed intentions and influencing the observed nurse. However, because the nurses were not trained in using TA, and not informed of the exact purpose of the study, there is still a risk of missed intentions. Grundgeiger et al. (2009) do not report the number of captured intentions, whereas Potter et al. (2005) present a time-weighted average of 11 and a maximum of 16 'stacked activities'. This is lower than the average of 20.4 intentions and the range of maximum PM load between 17 and 41 intentions that we found in this study. This difference could be due to a more accurate representation of intentions by using TA. In addition, in our study we logged all intentions, whether they were care-related or not, this was not the case in the study by Potter et al.

Furthermore, the use of TA led us to question how explicitly intentions for activities are formed. As an example, one of the first tasks all observed nurses completed when entering a patient's room for the first time that day, was to write their name on the whiteboard. Only two of the nurses have spoken this intention out loud. With the current data, it cannot be determined whether this intention was explicitly formed but not verbalized, or has not been in the nurse's mind until the moment the task was completed.

5.4.3 **Limitations**

Using TA is not easy. During the observations it was occasionally encountered that rather than speaking their thoughts out loud, the nurses would explain what they were doing and why. While this sometimes led to very useful insights, it was not an intended result. The decision to use TA rather than informing the nurses of our goal to measure PM intention increased the risk of missed intentions. We considered this risk to weigh less than the benefit of not influencing the nurses' behavior and PM performance by informing them of our focus.

Another limitation regards the self-report of task execution. We encountered a few cases in which the nurse reported a task to be executed in time, while we had seen that it was omitted during the observations, or vice-versa. The analysis of delays was solely based on the nurses self-report.

The observations were performed with a convenience sample of nurses willing to participate. This led to a group of relatively young nurses which is not the best representation of the target group. As PM performance has been shown to be affected by age, a recommendation for future studies is to look into the age factor. The observations were carried out in two wards of a single hospital, which limits the generalization of our findings.

5.5 Conclusions and implications for practice

The aim of this study was to explore the role of PM in missed nursing care. Over 40% of observed delays and omissions were, according to nurses' self–report, due to a PM failure. Based on this finding we conclude that improving nurses' PM performance has the potential to decrease missed nursing care and, therefore, improve patient safety and satisfaction.

It was observed that the PM load strongly increased during the first 30 minutes of the shift, after which a more or less constant level of more than 22 intentions was maintained. Delays occurred most frequently for time-based tasks, whereas omissions were most frequently reported for a novel type of PM task, the free PM task.

The findings in this chapter imply that training nurses' PM, which includes attention for the planning phase, is an interesting topic to explore further. Furthermore, the results of this study emphasize the need to educate (novice) nurses in prioritizing, as the perceived priority for an intended activity was shown to affect PM performance as well. Finally, the efficient use of reminders for important PM tasks should be further investigated.

6

Virtual Shift: Measuring the effect of sound on the forming and retrieving of prospective memory intentions

6 Virtual Shift: Measuring the effect of sound on the forming and retrieving of prospective memory intentions

In nursing, prospective memory failures are one of the underlying causes of care omissions. As care omissions have the potential to affect both patient safety and patient satisfaction, the prospective memory performance of nurses needs to be addressed. In prospective remembering an intention has to be formed to perform a future action. Then, this intention has to be encoded and finally, the intention has to be retrieved at the right moment. At the start of a nurses' shift, when reading electronic medical records, important intentions for care activities are formed. This is often done in a nurses' station while being exposed to intelligible background speech. Background speech is known to affect cognitive performance on several task types, but its effect on prospective remembering has not yet been reported. In the current chapter, the design, execution and results of an ecologically valid laboratory study are presented. This study aims to measure whether the forming of intentions and the retrieval of those intentions are influenced by the sound environment in which the intentions are formed. A novel experimental task combining a simulated electronic medical record and a board game was developed. A within subjects design was employed in which participants were exposed to three realistic sound conditions. The results indicate that the retrieving of prospective memory intentions is negatively influenced by the presence of intelligible background speech in a nurses' station.

6.1 Introduction

The general schedule of activities of nurses working in a surgical ward, especially in the morning, is fairly routine: administering medications, activities of daily living (ADL), wound care and a patient round with doctors. While executing these routine activities, several specific activities have to be performed for patients with a specific demand for care. Examples are deviating medication times, a daily change of bedlinen, asking a family member to agree upon restrictive measures, flushing a peripherally inserted central catheter and helping a patient to mobilize. Not executing these activities constitutes an error of omission, or 'missed nursing care' (Kalisch, 2006). Possible consequences of missed nursing care are poor patient outcomes, such as falls (Kalisch et al., 2012) and heart failure readmissions (Carthon et al., 2015). It may also affect nurses' job satisfaction (Kalisch et al., 2011a). Furthermore, missed (Lake et al., 2016), but also delayed (Hunt, 1999) nursing care has been linked to patient satisfaction.

Research on missed nursing care addresses multiple factors that may indirectly be responsible for omissions, such as a high work load (Ball et al., 2014), staffing problems (Cho, Kim, Yeon, You, & Lee, 2015; Dabney & Kalisch, 2015), and the work environment (Kim, K. et al., 2018). However, one of the actual mechanisms leading to omissions, failing to retrieve the intention for a specific activity (forgetting), has been relatively unexplored in the context of nursing. The results presented in **Chapter 5** indicate that over 40% of reported omissions were due to forgetting. Retrieving a previously formed intention, or remembering to perform a planned action at some future point in time requires prospective memory (PM)(McDaniel & Einstein, 2007). In prospective remembering, three aspects play a role. 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 (McDaniel & Einstein, 2007).

The main body of research concerning PM focusses on how factors such as age or brain damage influence a successful retrieval of intentions (Einstein & McDaniel, 1990; Mioni, Stablum, Mc-Clintock, & Cantagallo, 2012). PM performance is generally measured in a typical PM paradigm. In these experiments participants are working on a single, simple, ongoing task, such as watching a video or processing written text from a screen. While performing the ongoing task they have to remember to perform a PM task, such as pushing a button, either at a specific time (time-based PM task), or when a certain event occurs (event-based PM task). Examples of events in the event-based PM task are encountering a specific word on a screen during a reading task, or seeing an animal in the case of the video task. The participant receives clear instructions on the PM task prior to starting the ongoing task, no active planning is required from the participant. Only a handful of studies were found that do take into account the forming and encoding of PM intentions. The results of these studies suggest that the quality of the planning phase is important for PM performance (Kliegel, McDaniel, & Einstein, 2000; Kliegel, Martin, McDaniel, Einstein, & Moor, 2007).

The results from **Chapter 5** show that important intentions for care activities are formed at the start of the shift. At this time, nurses prepare for the shift by receiving a verbal 'change of shift report' from a colleague and reading patient files in the electronic medical records (EMR). The activities during this planning phase are often performed in a nurses' station in which the sound environment, especially during the overlap between the day- and the nightshift, can be very chaotic. Phones are ringing, colleagues enter and exit, chat about work or personal life and there are often multiple verbal reports between colleagues at the same time. Sound, and background speech in particular, is one of the aspects of the physical working environment that are known to influence various cognitive tasks (Clark & Sörqvist, 2012; Hughes & Jones, 2003). To our knowledge, no studies have been published that investigate the relationship between the sound environment and PM, which will be the main focus of the current study. The sound environment in a nurses' station may influence the forming and encoding of intentions, and therefore the correct retrieval of these intentions.

Typically, the influence of the sound environment on task performance is measured in a lab setting. A problem regarding the translation of laboratory findings to applied settings was elucidated by Sörqvist (2015) and defined as the “process impurity” problem. He argues that most cognitive tasks are process impure, meaning that task execution requires the involvement of many cognitive operations (or abilities). With some exceptions, the above applies to most tasks used in laboratory settings with the aim of studying basic cognitive functions. Complex tasks, those representative for work in applied settings, are, by definition, process impure.

The consequence of process impurity is that when the results of an experiment show an impaired performance due to sound, it is impossible to identify which basic cognitive process involved with the task was impaired by sound. Therefore, in order to determine which cognitive processes are impaired by sound, combinations of experiments with carefully selected task-requirement manipulations are required.

When, however, the goal is to study the effect of noise in applied settings, which is the case in the current chapter, both representative tasks and representative sound conditions have to be employed. Furthermore, the results of such studies should be interpreted on a behavioral level of analysis, not a cognitive level of analysis (Sörqvist, 2015).

This is in line with the work of Beaman, who recommends to consider the nature of the population exposed to the noise, the environment in which the sound occurs, the nature of the cognitive task and the sound sources when trying to reduce the negative effects of sound on task performance (Beaman, 2005). Therefore, to translate findings on the effect of the sound environment on PM performance to workplace recommendations, these contextual aspects should be accounted for in the design of a laboratory study.

This chapter presents the design, execution and results of an ecologically valid laboratory study. In this study, the experimental task resembles the cognitive task of a nurse, the sound conditions are exemplary for a typical nurses’ station and the participants are drawn from the actual population. We aim to measure whether the forming of intentions and the retrieval of those intentions are influenced by the sound environment in which the intentions are formed, and whether realistic interventions to the sound environment could make a difference.

Based on 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 retrieving of PM intentions.

6.2 Method

6.2.1 Participants

A convenience sample of twenty-eight female nurses (mean age = 32, S.D. = 9.85 years) working in various wards of one Dutch hospital participated in the experiment. All were native Dutch speakers and reported not to have any hearing deficits. An important inclusion criterion was for the participants to be familiar with the hospital’s EMR. They received a gift card worth €25,- for their time and effort. The nurses were recruited through an email newsletter and face-to-face during daily ward meetings. An informed consent form was signed by the participants before the start of the experiment. Written permission to conduct the study was granted by the hospital management, but due to the non-medical nature of the study, no further ethical approval was required.

6.2.2 **Design**

A within-subjects design was used with the sound environment in which the task is performed as the independent variable. Considering speech as the most important sound source in a nurses' station, a first logical intervention would be the removal of the speech source. Additionally, since a nurses' station can be quite reverberant due to large glass surfaces to allow a view of the ward, a second intervention concerns the room acoustic design of the nurses' station, which influences the speech intelligibility of the background speech and the overall sound level. The main parameters of the sound environment that are taken into account are the amount of sound absorbing material in the nurses' station and the presence of background speech. Based on these interventions, three sound conditions were modelled. Further elaboration on these conditions is presented in section 6.2.2.1

An experimental task called Virtual Shift was developed to measure the forming and retrieving of nurses' PM intentions. The task was designed to have a close resemblance to the daily work of nurses working in a hospital ward. In this task participants were asked to plan and remember to execute specific care activities for specific (virtual) patients. A consequence of using a within-subjects design was that different patient scenarios had to be used in each experimental trial. It was aimed to employ a counter-balanced design in which the order in which the sound conditions were presented, the order in which the patient scenarios were presented and the combination of patient scenario and sound condition were fully balanced across the subjects. The two main outcome measures are the number of formed PM intentions and the number of correctly executed PM tasks.

Virtual Shift consisted of two phases representing two distinct parts of a nurses' shift. In the first phase, the experimental task resembled the activity that nurses perform at the start of a shift: reading patient files. Participants were subjected to different realistic sound conditions, based on the interventions described above, during this first phase in which the forming of intentions was logged and measured. The first phase ended with two questions about the participants' perception of the sound environment. The second phase was a board game, designed to measure whether the formed intentions are correctly retrieved and therefore properly encoded. No experimental sound conditions were used during this second phase, the participants were exposed to the ambient environment of the experimental room. Each participant first received instructions, followed by a practice trial. Then, three experimental trials were run with each participant.

A graphical representation of the experimental design is shown in Figure 6-1. Each participant performed three experimental trials (trial 1, trial 2 and trial 3) after receiving the instructions and a practice trial.

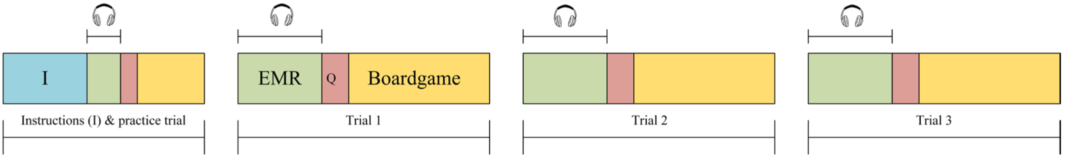

Figure 6-1 Experimental procedure. The figure shows the four stages of the procedure. The first stage consists of reading the instructions (I, in blue) followed by a practice trial. The remaining three stages are the three consecutive experimental trials consisting of reading the EMR (in green), the two subjective questions (Q, red) and the board game (yellow).

6.2.2.1 *Sound conditions*

Odeon 12.12 Combined was used to create the different sound conditions. Odeon is a comprehensive software tool to simulate and measure interior acoustics of buildings. Using Odeon, acoustics can be predicted, illustrated and listened to. A room of 20 m^2 was modelled after the nurses' station in the wards of the hospital from which participants were recruited. Figure 6-2 shows the actual room. Based on this model, two versions of the room were created with very different, but realistic room acoustic properties. The acoustic properties of the ceiling, and a 1 meter strip on the walls just below the ceiling were used to create the difference between room acoustic conditions. In the reverberant condition, these surfaces were modelled as plastered concrete while in the sound absorbing condition these surfaces were covered with mineral wool. Standard material properties from the Odeon materials library were used in both models, their properties are presented in Table 6-1.

Table 6-1 Surfaces and their properties used in the Odeon model.

Surface	Sound absorption [-] per octave band [Hz]								Area [m^2]
	63	125	250	500	1k	2k	4k	8k	
Floor	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.05	17.96
Lower part walls	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	15.6
Glass walls	0.1	0.1	0.07	0.05	0.03	0.02	0.02	0.02	14.3
Seat covers	0.4	0.4	0.5	0.58	0.61	0.58	0.5	0.5	4.04
Wooden panels below seats	0.3	0.3	0.3	0.15	0.13	0.1	0.08	0.08	1.36
Wooden closets	0.3	0.3	0.2	0.2	0.1	0.05	0.05	0.05	10.8
Desk	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	4,4
Upper part walls & Ceiling (absorbing)	0.15	0.15	0.7	0.6	0.6	0.85	0.9	0.9	32.8
Upper part walls & Ceiling (reverberant)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	32.8

Figure 6-2 The nurses' station in the hospital. The top image shows a large desk for nurses to work on with several computers. The encircled position is where the receiver is modelled in Odeon. The large windows, especially the one on the right, provides a view of the ward. The bottom image shows the other side of the nurses' station, with a small seating area, a window and a memo board. The computer on wheels shows that nurses use this seating area to work as well. The human sound sources in the Odeon model are situated in this corner, each on one of the orange seats.

In both versions, a receiver position was modelled behind a desk, facing the glass wall of the room (encircled in Figure 6-2). A line source, representing the ventilation system was also present, with the same properties in both versions. Furthermore, in both versions, the glass wall of the nurses' station looking out over the ward was modeled as a surface source representing the sound coming from the ward. The insulating properties of a typical glass wall were taken into account in the properties of these surface sources. Lastly, two human talkers were modeled as sources in a small seating area in the corner opposite the receiver (bottom picture in Figure 6-2). These two human talkers were modeled as if they were seated behind, and therefore out of sight, of the receiver facing the glass wall. To be able to create auralizations, impulse responses were calculated for each source-receiver combination. 6

Three sound conditions were created by convolving audio recordings with the calculated impulse responses. A pink noise signal was used for the ventilation sound, and an audio recording of the actual ward environment (not anechoic), containing distant voices, footsteps and doors opening and closing was used for the surface sources. The first sound condition, the ambient sound condition, was created from the impulse responses of the absorbing model, applying only the ventilation sound and the distant ward sounds. The second condition, the 'speech/absorbing condition' is based on the first, but here an anechoic recording of people talking was convolved with the human talker sources in the room. For the third sound condition, the 'speech/reverberant' condition, exactly the same sound sources were used as in the second condition, and convolved with the impulse responses from the reverberant model. To make the simulations suitable for playback through headphones, the built in Head Related Transfer Function (HTRF) combined with a headphone filter from ODEON were used. Although more advanced auralization methods, employing individual HRTFs for each subject, are available and would increase the plausibility of the acoustic scene (Oberem, Masiero, & Fels, 2016), the chosen method was considered more than sufficient for the current experiment's purpose.

Table 6-2 Overview of the sound conditions and their properties. RT refers to the T30 at 1000 Hz as calculated by Odeon. Both LA_{eq} and STI refer to the values at the receiver position

Condition	Odeon model	Active sound sources	Speech signal	LA_{eq} [dB]	STI [-]
Ambient	Absorbing (RT = 0.48s)	Ventilation, Ward noise	-	~32.4	-
Speech/absorbing (1)	Absorbing (RT = 0.48s)	Ventilation, Ward noise, human talkers	Conversation 1	~56.1	0.78
Speech/absorbing (2)	Absorbing (RT = 0.48 s)	Ventilation, Ward noise, human talkers	Conversation 2	~56.1	0.78
Speech/reverberant (1)	Reverberant (RT = 1.15s)	Ventilation, Ward noise, human talkers	Conversation 1	~61.0	0.61
Speech/reverberant (2)	Reverberant (RT = 1.15s)	Ventilation, Ward noise, human talkers	Conversation 2	~61.0	0.61

Since a repeated-measures design was employed in this experiment, and participants were to be exposed to all three sound scenarios, two recordings of speech were necessary to avoid having to listen to the same conversation twice. This means that for the 'speech/absorbing' and the 'speech/reverberant' condition, two versions were created based on two recorded conversations. Two volunteers, female co-workers at the university, were asked to read from a script that was based on actual conversations between nurses in the hospital. Both conversations included a change of shift report, and a longer discussion about a specific patient. The conversations contained little pauses and lasted 13 minutes. One conversation started with some personal chatting, while the other conversation ended with personal chatting. None of the patients that were discussed were related to the patient scenarios created for Virtual Shift.

The speech signals that were used in the speech scenarios were recorded in a semi-anechoic room using a 'Rode NT-SF1 ambisonic' microphone connected to a TASCAM recording device. It was decided to use 1 recording with both persons in the room, being able to see each other, to make the conversation sound as natural as possible. This also means that sometimes the two talkers interrupted each other, or were talking at the same time. A limitation of this method was that the voices of the two talkers could not be separated. In the result, the convolution of each main talker also contained the speech of the other talker, but at a slightly lower level.

A Head and Torso simulator (B&K 4120-C) was used to calibrate the sound pressure levels of the separate sound sources and the resulting sound scenarios that were to be offered by headphones (Sennheiser HD 380 pro). The audio was played back using a Python script that was written for the calibration, containing the same code that was used to play the audio during the experiment. The headphones were connected to a laptop via an external sound card (ST Lab USB sound Box). The same setup was used during the experimental sessions.

6.2.3 **Development of the experimental task**

6.2.3.1 ***Experimental phase 1: Forming and encoding intentions***

In order to create a close resemblance to reality, screenshots of the Dutch hospital's EMR (a scrambled version used for educational purposes) were used to simulate an EMR for participants to browse through in a controlled manner. The simulated EMR was built by linking the screenshots using the Python programming language. It was designed such that it appeared to have the same functionalities as the actual EMR. Pink boxes were used to indicate which links in the EMR were active and could be 'clicked'.

Scenarios

Three patient scenarios were required to be able to employ a within-subjects design. To create these scenario's, the orthopedic ward was selected of which the information of the 'currently' admitted patients was analyzed based on their age, sex and the number and content of activities that had to be performed for each patient during the board game. From this ward, ten patients were selected to create three scenarios of three patients that contained an equal number of PM tasks. The tenth patient was used to create a practice scenario. Each scenario consisted of one male and two female patients, with different ethnic backgrounds. The number of patients that are within a nurse's care depends on several factors such as the type of ward, hospital management and perhaps even cultural differences. While in this specific ward, a nurse can be responsible for up to ten patients, it was decided to limit this to three as not being able to actually see and talk to the patients introduced an extra difficulty. Another reason for creating scenarios containing 'just' three patients was that in this experiment, a participating nurse could not depend on colleagues or external cues. For example, seeing an almost empty drip-feed could provide an external cue for a nurse to replace it. Such cues were not included in the board game. In the results section, the patient scenarios are referred to as scenario A, B and C. At the start of each experimental trial, a 'patient note', this was a printed sheet with basic information on the three patients (name, reason for admission, their history of care, allergies and whether they had a drip-feed), was given to the participants. It was common practice in the collaborating hospital to provide nurses with a similar sheet at the start of their shift.

EMR

The simulated EMR's first screenshot is a ward overview, Figure 6-3, showing the currently admitted patients on a date in the past. The date was determined by the date on which the scrambled version of the EMR was created from the actual EMR. Depending on the scenario, three patient names are boxed. For these patients, screenshots of all relevant information can be accessed by clicking on the patient's name. The simulated EMR contains an 'action plan' showing which protocols are running and which activities have to be performed (a to-do list), information on infusions, a graph of the patients' vital measurements, daily reports, a log of medical conversations, a medication list, pending questions, and assignments. Not all the pages and functionalities of the actual EMR were included in the simulated EMR. For example, in the actual EMR, clicking on the measurement points in a patient's graph of vital measurements would show the exact value of that measurement. This was not the case in the simulated version. Furthermore, pages that were considered not essential for the planning of care were not accessible.

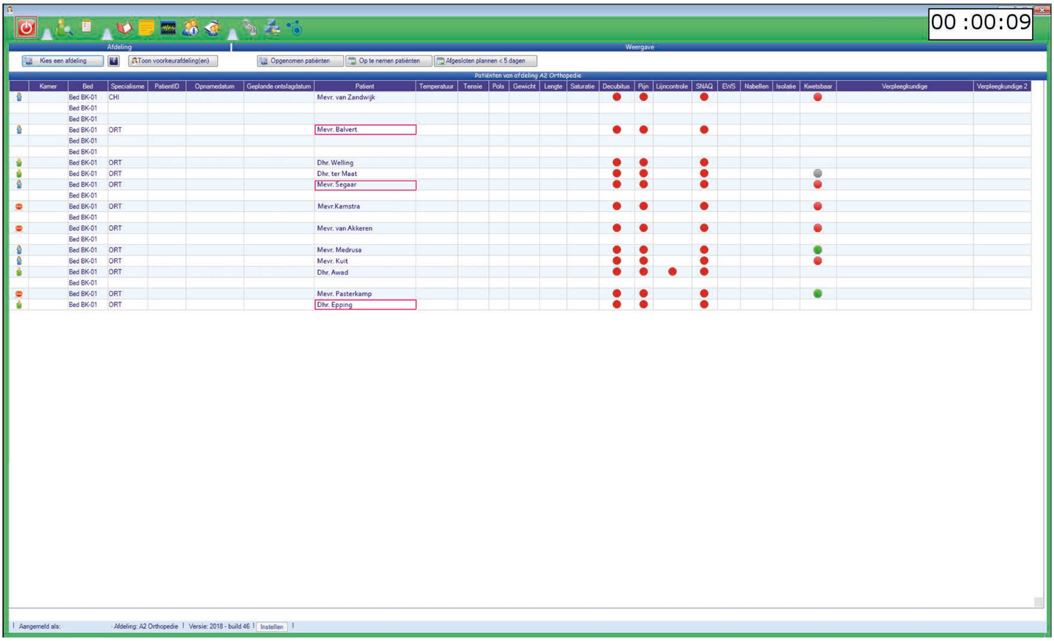

Figure 6-3 EMR ward overview in which the three patients that belong to the current patient scenario are boxed. The boxes indicate that these names can be ‘clicked’ to access the corresponding EMR. The columns show, from left to right, whether the patient is male, female or waiting to be transferred to another care facility, the room number (removed), the bed number, the assigned surgical specialism, the patient ID (removed), date of admission (removed), planned date of discharge (removed), the patient’s name (random fictional names), their vitals and other patient information (14 columns, not up to date in the scrambled version) and the names of assigned nurses (2 columns, removed).

All staff names were removed from the screenshots, and the (already scrambled) names of the patients were replaced by random names. Dates of birth and references to places of residence or other care facilities were removed. To provide visual recognition, avatars were created for each patient and added as a ‘profile picture’ to each screenshot. Figure 6-4 shows the ‘action plan’ of one patient.

The PM intentions that are to 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. A third type of PM task, defined as a ‘Free PM task’, was created based on the analysis of the EMR. The action plans of the different patients contained several tasks that were not due on a specific time, or related to a specific event, but had to be performed at some point during the shift. Examples are to bring a patient a ‘cold pack’ or to flush a cannula on a daily base. Defining these ‘free’ PM tasks was based on the findings in **Chapter 5**.

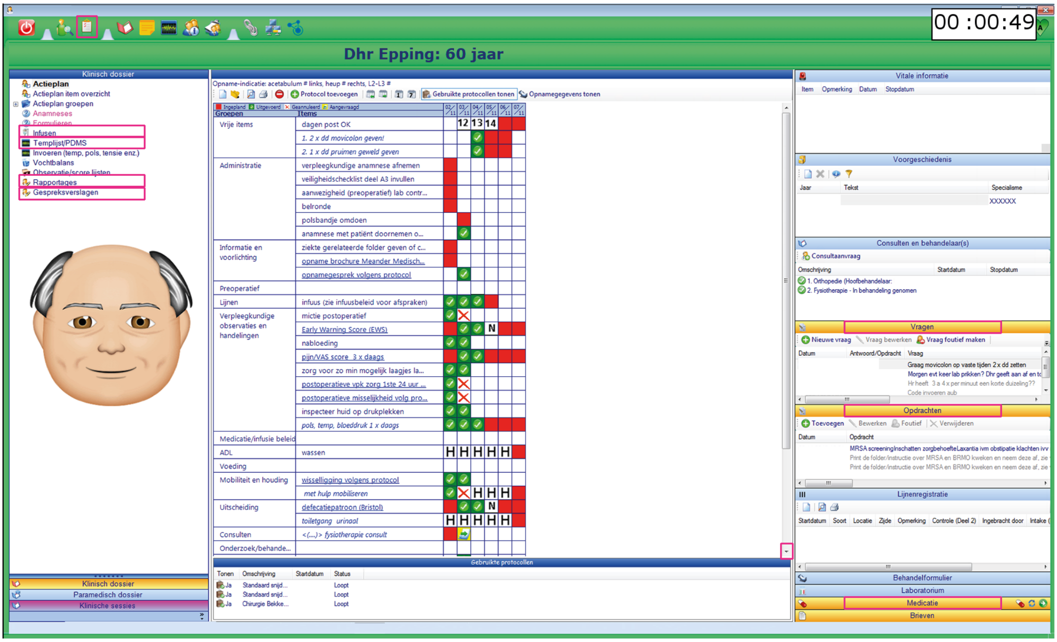

Figure 6-4 EMR screenshot of a patient's action plan. The horizontal menu bar in the top (green background) shows the EMR's functionalities. The only active option is the boxed button that links back to the ward overview. The menu on the left shows the links to other pages in this patient's EMR, only the boxed links are active. The panel in the middle shows the action plan. It is a list of actions and protocols that have to be performed for this patient. Each column represents a date, with red squares indicating that a task has to be performed on that day. A nurse can update the action plan (in the actual EMR, not in the simulated version) by marking an action as 'done' which results in a green square. The letters in some rows provide extra information on the action, in the case of this patient for example, an H is shown for the activities of washing, toileting and mobilizing, indicating that this patient needs the nurses help for these activities. The menus on the right show, from top to bottom, the patients vital information (removed), the patients history (removed), the involved specialisms, a preview of pending questions, a preview of pending assignment and links to information about infusion lines, treatment forms, lab results, medication and letters. Only the links to pending questions, pending assignments and medication are active, as indicated by the pink boxes.

'Excluded tasks'

The action plans, which form a to-do list for the nurses, can contain up to 25 tasks for a single patient on a particular day. These include protocols that have to be followed, checklists for observations and administrative tasks. To limit the number of PM tasks for the participants to a number that can be expected to be remembered, all administrative tasks and all the tasks related to an observation or inspection were excluded from the experiment (in the remaining text referred to as 'excluded tasks'). This was made clear to the participants in the instructions before the experiment and in a written note that was visible to them during the experiment.

PM tasks

Each patient scenario was designed to contain twelve, very clear, PM tasks. This number was lower than the average PM load that was presented in the results of the observation study in **Chapter 5** (20.4) but is close to the time-weighted average of eleven stacked nurses' activities presented by Potter et al. (Potter et al., 2005) The twelve tasks include two time-based PM tasks, three free PM tasks and seven event-based PM tasks. The time-based tasks were randomly set on different virtual times for each scenario. The event-based tasks were either linked to routine activities that were performed for patients every day, such as medication administration, ADL care and doctors' rounds, or to more specific events. For example, in one scenario a urinary sediment had to be retrieved from one of the patients. To be able to do this, the patient would have to go to the toilet. This would be the linked event for this specific PM task. In the instructions that the participants received before starting the experiment, the general schedule of care activities in the ward were explained. It was made clear that in this ward, the nurses always start with a medication round, followed by helping patients with activities of daily living (ADL). After the ADL care, a doctor would enter the ward to visit each patient with the nurse. In the instructions it was also made clear which type of event-based PM tasks were to be performed during which routine activities. For example, in this ward, measuring vitals would have to be performed first thing in the morning, when entering the patient room with medication. Some edits to the original EMR were necessary to create an equal number of PM tasks, such as changing the date of activities that had to be performed every other day.

Measuring intentions

In order to measure whether the intentions for each PM task is formed, participants are instructed to plan aloud during this part of the experiment, allowing the researcher to record and log the intentions that are formed.

Time limit

Participants were informed that they would have to spend a minimum of eight minutes and a maximum of ten minutes on this first experimental phase.

6.2.3.2 ***Experimental phase 2: Retrieving intentions***

Virtual Week

The objective of the second phase of the experiment was to measure whether the formed intentions were retrieved during the correct window of opportunity. To this end, 'Virtual Shift' was designed, which is a transformation of an existing PM laboratory task called 'Virtual Week'. Developed by Rendell and Craik, 'Virtual Week' is a board game that measures PM performance with a close resemblance to everyday life (Rendell & Craik, 2000). By rolling a die, participants move their token along the squares of a closed-loop track on the board. One loop represents the waking hours of one day, and the position of the token within the loop corresponds to the time of day. Seven loops, representing one week, need to be finished to complete the game. While moving the token across the board, 'event-squares' are passed which are placed in the loop at a regular interval. Landing on or passing an event-square triggers a pop-up description of an event that represents a typical daily-life activity. Examples are meals, a shopping trip or receiving a phone call. For every event, the participant is asked to answer a multiple-choice question about that event. For example, in the case of a meal, the question would be whether the participant wants water, coffee or tea to go with the meal. During each virtual day, ten events pop up. Instructions regarding which PM task has to be performed when, are presented to the participants before the start of the game, and in between each virtual day. These PM tasks are to be executed at a specific time, or when a certain event occurs. Taking medication with breakfast (when the event 'breakfast' pops up) for example, or calling a family member at 16.00 pm. Virtual Week has proven to be a valid measure of PM performance for various situations (Mioni, Rendell, Stablum, Gamberini, & Bisiacchi, 2015; Rendell & Henry, 2009).

Virtual Shift

In the current study, Virtual Week was transformed into 'Virtual Shift'. In Virtual Shift, three loops on the board have to be finished, corresponding to the first three hours of a nurses' day shift. There were still ten events in each loop, now representing the typical events and activities that occur during these first three hours of the shift. The descriptions of the events correspond with the patient scenarios that were created for the first phase of the experiment. Each event can, but does not have to be, linked to a to-be-performed PM task. The consecutive events are to be seen as a narrative for the participants' shift, informing them where they are. All routine activities, the morning medication round, ADL and patient rounds were included as events for each patient. For each scenario in the board game, these events appear in this order. In the first 30 to 60 virtual minutes, the events related to medication rounds pop up. For every patient, there is one event describing the activity of entering the patient room to administer medication, and a second event describing the activity of leaving that patient's room. Then, after 30-60 virtual minutes the events describing the ADL care activities for each patient pop up. Again, there is one event describing entering the room, and a second event describing leaving the room. In the last virtual hour the events are related to the doctors' rounds. Each patient room is entered with the doctor in one event, and exited in a next event. In between these activities, other events occur. For example a phone call from the pharmacy, a patient call, or a visitor asking for directions. As in the original game, a multiple-choice decision has to be made by the participant for each event. An example of an event, translated to English (Virtual Shift is in Dutch) is shown below.

"You are entering the room of Mrs Balvert 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 decision options to make regarding this event are to ask her whether she wants to try reducing the pain medication, to suggest sticking to the current dose, or to increase it. 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. As mentioned before, 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.

The description of the events and the multiple-choice options linked to these events were derived from the data from the observations described in **Chapters 3-5**. The descriptions of activities in the observation logs and the audio files were scanned to identify typical events and common decisions based on these events.

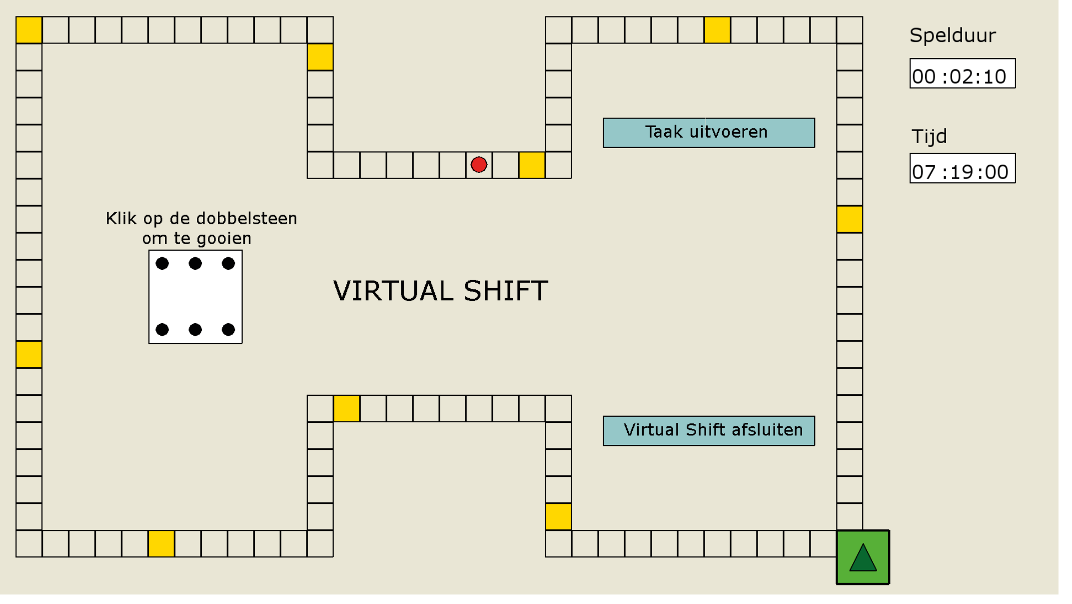

Figure 6-5 The layout of Virtual Shift's digital cardboard. The yellow squares indicate the event-squares. The green 'start-square' also constitutes as an event-square. The teal button in the top-right corner of the cardboard is the 'execute task' button, the teal button in the bottom-right corner of the cardboard exits the game. The die can be clicked to throw it.

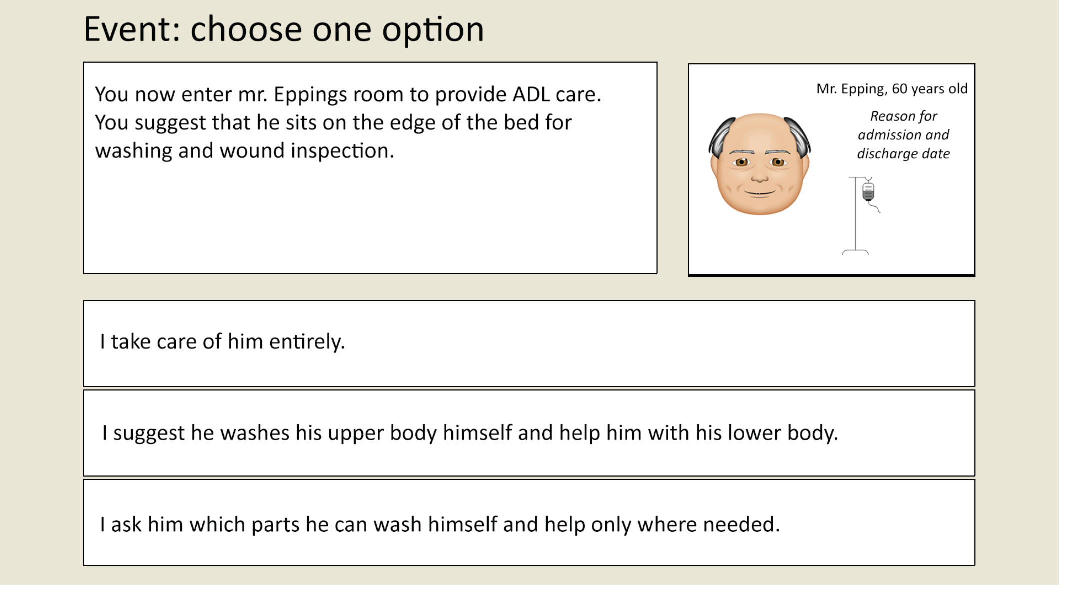

Figure 6-6 The layout of an event card, translated to English. It shows the description of the event (top-left box), the avatar of the patient that this event is about, including some basic information about the patient (top-right box), and the descriptions of three choice options (three bottom boxes)

A digital version of Virtual Shift was created using Python. The layout of the digital cardboard, which is very similar to the original game, is shown in Figure 6-5. Clicking the die causes it to roll, after which the token automatically moves to the next position. The events pop up whenever the token lands on, or passes a yellow square (Figure 6-6). The pop-up screen with the description of the event disappears after clicking one of the provided options. Two digital clocks are always visible on screen. The first clock shows the amount of time (realtime) that has passed since Virtual Shift was started; the second clock shows the virtual time which corresponds to the position of the token on the board. This time represents the time during the shift. In order to perform a PM task, the 'perform a task' button can be clicked which launches another screen that allows the participants to type the task they want to conduct. The tasks are logged with a virtual time stamp and used to calculate PM performance.

1.1.1.3 **Validation**

Prior to the final data collection, two pilot phases were carried out to improve face, content and ecological validity. The first pilot was performed with two senior nurses of the collaborating hospital. The aim was to validate the simulated user interfaces of the EMR and the board game, the instructions, the PM tasks and the event descriptions. First, the experimental task was performed by the two senior nurses in an informal setting. They were asked to complete a full experimental trial and were given a pen and paper to mark any questions or uncertainties that raised during the trial. After the trial, a discussion between the researcher and the two nurses followed on possible points of improvements. In this discussion, the researcher asked whether the instructions were clear, whether all the pages required to plan care were accessible in the simulated EMR and whether it was clear to them which task they would have to remember to execute and when. Audio recordings were made during the entire session. The time required to read the EMR and to play the board game was recorded as well.

During this pilot phase, the medication list in the EMR was not up to date, but the other functionalities described above were active. Both nurses stated that, while it was their habit to check some clinical information that was not accessible in the simulated EMR, the current version was sufficient for them to plan care. The only exception was the incomplete medication list. After the pilot session, the two nurses compiled a realistic medication list for each patient which was included in the EMR.

The user interface of the board game was perceived as intuitive by the nurses. In general the event descriptions and the corresponding multiple-choice options were found realistic. Some minor comments and suggestions were made regarding the event descriptions which were incorporated in the final version.

Major changes in the experimental task were based on comments regarding the instructions and the content of PM tasks. Here, the main issue was the distinction between the 'excluded' tasks and tasks that were to be performed during the board game. The written instructions were updated and reviewed by the two nurses after the pilot. Furthermore, some PM tasks were removed while others were added.

A second pilot phase was conducted with the first 6 recruited participants who performed the experimental task in the final setting. After these 6 participants, two additional measures were taken to lessen the mental burden of the experiment. The 'patient note' was added to the experiment. This paper note was now provided at the start of each trial to prevent the participants from forgetting the patient's names. The note also showed whether a patient had a drip-feed, which is something they would normally see when entering a patient's room. Another note was placed within the participants' view, containing a list of 'excluded tasks'. The 6 participants were excluded from further analyses.

6.2.4 **Subjective measures**

After completing phase one of each experimental round, the participants were asked to what extent the background sound had disturbed them while reading and to what extent they expected the background sound to impact their reading performance. Answers to both questions were given on a 5-point response scale with the following verbal indicators: “not at all - a little – considerably – very - extreme”.

6.2.5 **Procedure**

Participants were seated behind a desk in an enclosed office on the seventh floor of the hospital. The experimenter (author) was in the same room during the whole procedure. The room looked out on the roofs of lower parts of the building and a distant road. A laptop containing the experimental software was connected to a monitor in front of the participant. During the first phase of each experimental round, reading the EMR, the participant was wearing a headphone. Figure 6-7 shows the experimental setup and a participating nurse playing Virtual Shift.

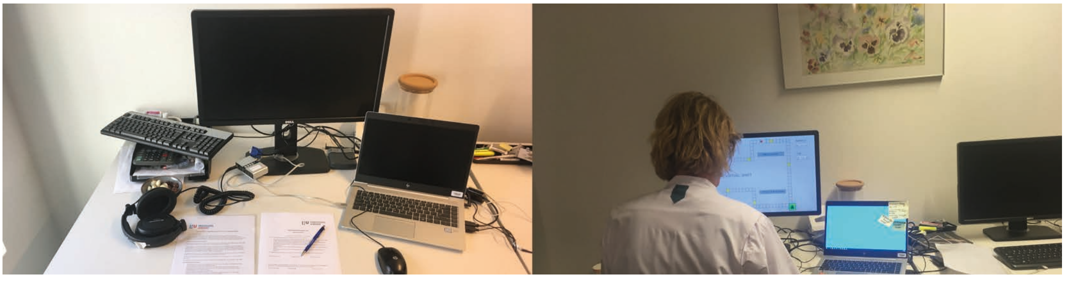

Figure 6-7 Experimental room and setup. The left image shows the main computer screen to which the laptop that was used to run the experiment was connected. Participants had to use the laptop keyboard to type in the PM tasks they wanted to perform. The right image shows a nurse participating in the experiment. The main screen shows the layout of the board game.

Before the start of the experiment, the participants were informed that they would go through three experimental trials which were preceded by instructions and a practice round. They were allowed, encouraged even, to ask questions during the instructions and the practice trial to make sure everything was clear, as no questions could be answered during the experimental trials. Instructions were presented on screen, followed by a verbal instruction based on a checklist by the experimenter. The verbal instruction was a repetition of some important aspects of the on-screen instruction. After the instructions the participants could click a ‘start’ button to open the EMR which would automatically cause the audio file to play. The participants were instructed to plan aloud while reading the files. During this first phase, the intentions for actions to be performed that were spoken out loud were marked on a checklist by the author. An audio recording was made to double-check for missed intentions. Participants were instructed they had to spend a minimum of eight minutes and could spend a maximum of ten minutes on reading the EMR. Closing the EMR early caused a warning message to pop up. If the participants exceeded the ten minutes, reminders were given but the EMR was not closed automatically. When the participant had finished reading the files, they could return to the ward overview and exit the EMR. When closing the EMR the participants were asked to answer the two questions about the sound environment and the experimental task.

Immediately after finishing the first phase of the experiment, the second phase was started. During this phase, the board game, no headphones were used. After three circuits on the board game, the final 'event' that popped up informed the participants that they had finished their shift. After each scenario a short break was held. On average, participants took 20 minutes to finish the game. The whole experimental session lasted around 2 hours and 15 minutes.

6.2.6 Method of scoring and analysis

The current experiment, while adapted from Virtual Week, has not been used in the context of nursing before. Rather than receiving an explicit list of tasks, as in Virtual Week, in Virtual Shift nurses had to read the EMR and form intentions based on the provided information. Furthermore, in Virtual Shift, the participating nurses could not choose a to-be-performed task from a list of tasks but had to rely on their retrospective memory regarding the content of tasks. This was not the case in Virtual Week.

To support the exploratory analysis of results, a log of general observations and remarks from the participants was kept by the author during the experimental session.

6.2.6.1 *Dependent variables*

In the first phase of the experiment, the number of formed intentions was retrieved from the checklist that was used to log the formed intentions. As there were 12 tasks in each patient scenario, the maximum score for a participant was 12. In the second phase of the experiment, each intention was labeled as 'on time', 'late', 'very late', 'early', 'very early' or 'omitted'. The decision criteria for this label are shown in Table 6-3. Three outcome measures were determined based on the results. A 'non-omission' score, scoring each performed task, independent of their timely retrieval as 'retrieved'. An 'on time' score, scoring only the tasks that were labeled as 'on time', and a 'weighted score', based on the criteria in Table 3. In the 'weighted' score, early retrievals were scored lower than in-time retrievals, but higher than late retrievals.

The PM tasks in this experiment contain an important retrospective element. As in reality, a nurse has to remember to do something at the right time, but the content of what has to be remembered is key too. In the case of discussing restrictive measures for a patient with the relative of that patient, the nurse first has to remember that something has to be discussed once they encounter the relative of a patient. This automatically means that they have to remember for which patient the intention was formed. On top of this, the nurse has to remember the topic of discussion: the restrictive measures. Therefore, the content of each retrieved PM task was also labeled as correct or incorrect. The scenarios of patients were designed such that there were no PM tasks that had to be performed for all three patients. There is a maximum of two patients in each scenario who's vitals have to be measured or need fresh bedlinen. If such an action were performed for all patients, the content of the correct actions were scored incorrect. If the participant remembers that a question from the EMR has to be discussed with the doctor, but the content of the question is missing the retrospective content was also scored as incorrect. Finally, any action that was described correctly but the patient's name was missing or wrong was scored incorrect based on content.

Three combined prospective and retrospective (PM/RM) scores were calculated from the 'non-omission' score, 'on time' score and the 'weighted score' counting only those tasks for which the content was scored as correct.

Table 6-3 Scoring of retrieved intentions.

Label	Task type			Weight
	Time-based	Free	Event-based	
On time	T -3 min > X < T + 3min	always	After E, before next roll of die	1
Late	T + 3 min > X < T + 1 h	n/a	X<E+1h	0,5
Very late	T + 1 h > X < Within VS	n/a	E + 1 h >X < Within VS	0,25
Early	T -3 min < X > T - 1 h	n/a	X>E-1h	0,75
Very early	T -1 h < X > Within VS	n/a	Within VS	0,5

Note. X is the moment at which the PM task is performed by the participant. T is the time at which an PM task should be performed. E is the event linked to the event-based task. Times refer to virtual time.

6.2.6.2 ***Statistical analyses***

The statistical software SPSS 25 was used to analyze the data. An exploratory analysis was performed on the frequency of forming and retrieving intentions for each PM task. Furthermore, we analyzed the participants comprehension of Virtual Shift by the number of non-omissions and the number of 'excluded tasks' that were performed during the board game. Following the results of this exploratory analysis, generalized linear mixed models (GLMM, for the binary outcome measures) and linear mixed models (LMM, for the weighted scores) were used to discover effects of sound condition. This was motivated by the experimental design, in which the participants are sampled from a nursing population, and the PM tasks in each scenario are sampled from a range of possible PM tasks. This means there are two sources of correlation for the outcome measures, and it is our aim to generalize the outcome measures over both. This requires a method in which crossed random effects can be modelled (Raaijmakers, Schrijnemakers, & Gremmen, 1999). Additionally, while conditions, PM tasks and their order of presentation were counterbalanced across the participants, practice effects may still occur. The use of (generalized) linear mixed models allows to take such effects into account (Bell, Lamport, Field, Butler, & Williams, 2018).

The data was entered in SPSS in the long format, with each row representing one PM task, thus creating 36 rows for each participant (12 tasks per scenario). For the forming of intentions, the 'on time' scores and the 'non-omission' scores, a model was fitted based on a binary outcome with a logit link function. The weighted scores were best represented with a linear mixed model. In all the models, sound condition and trial number were modelled as fixed effects. The weighted scores were used to find the best model fit. Here, a step by step approach was used, increasing the complexity of the model in the following order. First, random intercepts were modelled for participants. Then, random intercepts were modelled for PM tasks. Following this, random slopes for the participant by sound condition, which would account for individual effects of sound for each participant were included. This last inclusion caused convergence issues in the model of the 'weighted' PM scores, and did not significantly improve the model fit in the analyses of the combined RM and PM scores. No interaction effects were assumed for sound condition by trial number and sound condition by PM task. To allow for a good comparison of the different outcomes, the structure of the GLMM models for the binary outcomes were based on the LMM model for the weighted outcomes. Here, using SPSS 25, the Satterthwaite approximation for degrees of freedom was used, which is recommended when the sample size is small and data are unbalanced (Heck, Thomas, & Tabata, 2013). The tests of fixed effects and coefficients were based on a robust estimation to handle violations of model assumptions (Heck et al., 2013). This model is similar to the proposed model for the Latin Square design in (Baayen, Davidson, & Bates, 2008).

Friedman's tests were used to assess differences between perceived disturbance and perceived effect on performance for the different sound conditions.

For all analyses, statistical significance was set at $p = 0.05$, and the confidence level at 95%.

6.3 **Results**

In total, 28 experimental sessions were completed in a two months period. Table 6-4 and Table 6-5 show the number of participants for each possible order and combination of scenarios. With five sound conditions (1x ambient, 2x speech/absorbing and 2x speech/reverberant), three patient scenarios and six possible orders of presentation for both conditions and patient scenarios, a fully balanced design would require 72 participants which was not considered feasible. In the counterbalancing table, priority was given to the order of presentation for sound conditions and the combinations of scenario and sound condition. For the order of presentation of patient scenarios, it was decided that the number of participants receiving scenario A before scenario B should be equal to the number of participants receiving scenario A after scenario B. The same logic was applied for the order of presentation for scenarios A and C, and B and C. A schedule was developed containing 48 possible combinations. The assignment of participants to a specific combination was based on the order of recruitment. As a result of participants not showing up and reaching the maximum number of willing participants, only 28 of the 48 possible combinations were filled, leading to a slightly unbalanced design.

A noteworthy difference is the number of participants receiving the speech/absorbing sound condition during the first, second and third experimental round, which deviate from the numbers for the ambient and speech/reverberant conditions. Furthermore, 13 participants received patient scenario B during the first experimental round, compared to 8 participants who received scenario A and 7 who received scenario C.

Table 6-4 Number of participants in each trial-sound condition combination and each trial-scenario combination.

	1st	2nd	3rd
Ambient	10	10	8
Speech/absorbing	7	8	13
Speech/reverberant	11	10	7
Scenario A	8	12	8
Scenario B	13	0	15
Scenario C	7	16	5

Table 6-5 Number of participants in each combination of scenario and sound condition.

	Ambient	Speech/absorbing	Speech/reverberant
Scenario A	9	8	11
Scenario B	9	11	8
Scenario C	10	9	9

6.3.1 General observations during the experiment

The log that was kept during the experiments was used to gain insight in how participants dealt with the experimental task. Based on this log, two important impressions are reported below.

First, remarks and actions of a few participants led to the assumption that they had not fully understood what was asked of them. For example, when planning aloud and reading the EMR, some of the participants focused on the ‘excluded tasks’, despite being explicitly informed that they were excluded from the experiment. Instructions regarding these ‘excluded’ tasks had been given in the on screen instructions, the verbal repetition of instructions and the note that was visible for them while reading the EMR. Examples are administrative tasks, and actions related to discharging a patient. After the first experimental round, one of the participants mentioned that knowing which tasks had to be remembered and which not was something that made the experiment more difficult.

Another example concerns tasks that were to be performed for more than one patient during the board game, such as taking vitals (to be performed when the event of entering that patient’s room during medication rounds) or discussing something with a doctor (to be performed when the event of entering that patient’s room with a doctor during visiting rounds). In a few occasions, such tasks were completed at the start or halfway the medication/visiting round for all the patients at once, resulting in either early or late retrievals. One of the participants mentioned “the penny dropping” during the first experimental round, when, after having completed a few tasks too early, recognizing the correct window of opportunity for these tasks. This remark stresses the importance of including trial number as a fixed effect in the analyses.

Second, while listening to the participants planning aloud, it became clear that intentions were rarely formed for some of the tasks that were embedded in the patient scenarios. Based on these observations, it was decided to look into task execution for tasks that were excluded, individual cases with very low scores, and the differences between patient scenarios.

6.3.2 **Exploratory analysis of results**

6.3.2.1 ***Effect of patient scenario***

While all patient scenarios contained an equal number of time-based, event-based and free intentions, there is a possibility that not all intentions were as easy to be detected in the EMR. There are also several factors that could possibly cause differences in retrieval scores, such as the perceived importance of the tasks, the complexity of the retrospective content or the presence of cues in the event narratives of the board game. If correct retrieval is dependent on the PM task itself, it would mean there is an 'effect of PM task'. Figure 6-8 shows the frequency of formed and retrieved intentions (non-omissions) for the three scenarios. The reason for showing the non-omissions and not the in time retrievals here is our expectation that an effect of PM task is more likely to be due to the content of the intentions than due to their window of opportunity.

Overall, the mean number of formed intentions in scenario A is 9.11 compared to 8.97 in scenario B and 8.86 in scenario C. The mean number of retrieved intentions in scenario A was 7.43 (5.25 were on time), compared to 6.39 (4.32 were on time) in scenario B and 6.57 (4.43 were on time) in scenario C. From Figure 6-8 however, it can be seen that within each scenario, there is a high variation of formed and retrieved intentions. For example, the intention for PM task F1 in scenario B was only formed by 5 participants and retrieved by none. These results stress the importance of including PM tasks, rather than scenario, as a random effect in our subsequent analysis. This means that a random intercept is included in the statistical model for each individual PM task.

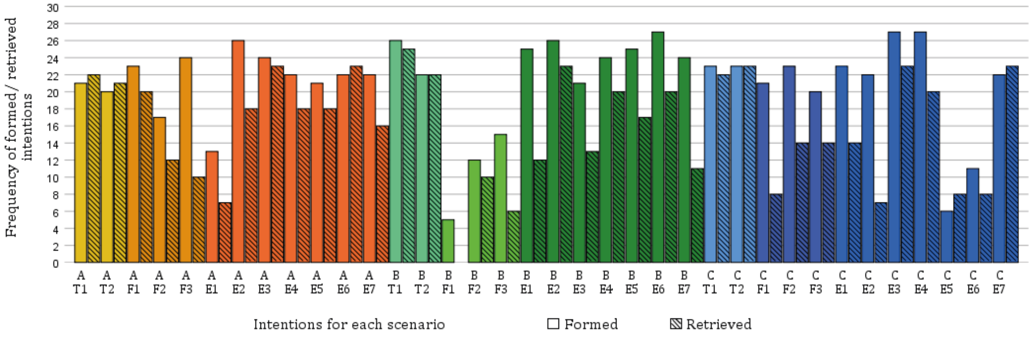

Figure 6-8 Frequency of formed and retrieved intentions for each task in each scenario. For each PM task it is shown how many participants have formed the intention and how many participants retrieved the intention. The PM tasks are indicated by the scenario in which they occur (A, B or C) and whether they are a time-based, free or event-based PM task (T, F or E) and their individual number.

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6.3.2.2 ***Effect of very low scores and misconceptions***

Very low scores

Figure 6-9 shows the distribution of the sum of non-omissions of the three experimental conditions. On average, participants retrieved 20.4 (S.D. = 5.29) intentions during the board game. Figure 6-9 shows one extreme value with a total non-omission score of 6. The research log for this participant revealed that when reading the EMR, several pages were skipped and the participant tried to close the EMR multiple times before the 8 minutes were over. In one scenario this happened after three minutes of reading. This observation, combined with a score that deviates from the mean by more than two standard deviations motivated to perform an additional analysis excluding this participant.

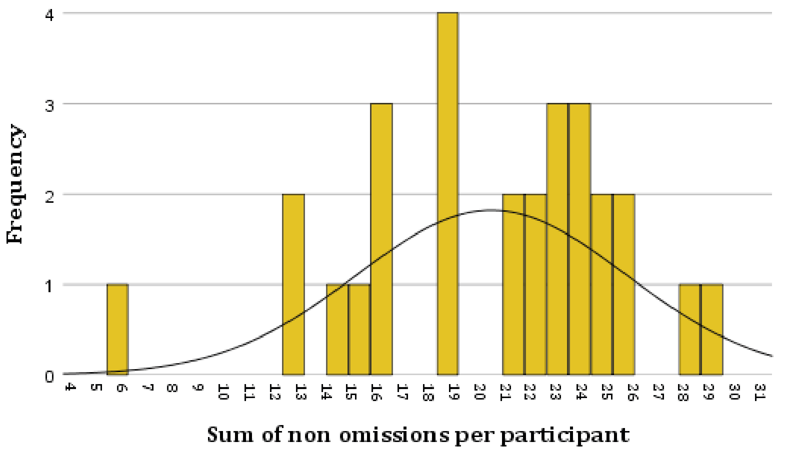

Figure 6-9 Frequency of summed non-omission scores per participant.

'Excluded tasks'

Besides looking into very low scores, an analysis was performed looking into the number of 'excluded tasks' that were still performed during the board game. For each full experimental session, the non-omission score was divided by the number of excluded tasks that were performed to calculate the ratio between included and excluded tasks. The mean ratio was 0.33, with values ranging from 0.04 to 1.24. Two participants had a mean ratio (for the three experimental rounds) higher than 0.75, indicating that over 40% of their retrieved PM tasks were excluded tasks. The assumption was made that the scores of these participants are not representative for their PM performance.

Figure 6-10 shows for each participant the number of non-omissions across all three trials. The included tasks are shown in yellow and the 'excluded tasks' are shown in blue. The participants with extreme values, meaning a very low total score, or a very high ratio of included/excluded task are marked.

Based on these results, we will present two separate analyses on the effect of sound condition on the forming and retrieving of PM tasks. One including all participants, and one in which three participants were excluded based on their low non-omission score, or their high (>.75) ratio between included and excluded tasks.

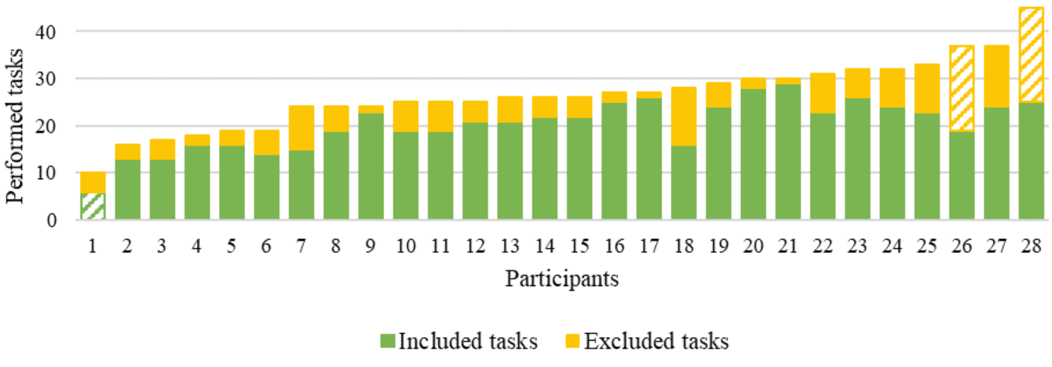

Figure 6-10 Number of non-omissions per participant across trials. The stacked bar chart shows the 'included tasks' in green and the 'excluded tasks' in yellow. The participants whose scores are given by bars 1, 26 and 28 are excluded based on their extremely low score (1) or the high ratio of excluded/included tasks (26, 28).

6.3.3 Forming and retrieving intentions in different sound conditions

6.3.3.1 *Overview of outcomes in different sound conditions*

Table 6-6 provides an overview of the average number of formed and retrieved intentions per nurse in the different sound conditions. The number of retrieved intentions is consistently lower in the speech/absorbing condition compared to the ambient and the reverberant conditions.

6

Table 6-6 Mean number of formed and retrieved intentions, including standard deviations, in the three sound conditions. Forming intentions was measured in while reading the EMR, retrievals were measured during the board game.

	Outcome	Sound condition		
		Ambient	Speech/absorbing	Speech/reverberant
N=28	Forming intentions	8.86 (1.78)	8.89 (2.13)	9.25 (1.78)
	On time (PM)	5.07 (2.16)	4.18 (2.37)	4.75 (2.55)
	On time (PM/RM)	4.57 (2.25)	3.82 (2.48)	4.11 (2.51)
	Non omissions (PM)	7.07 (2.16)	6.43 (2.23)	6.89 (2.27)
	Non omissions (PM/RM)	6.14 (2.38)	5.36 (2.48)	5.57 (2.77)
	Weighted (PM)	6.28 (2.08)	5.55 (2.11)	6.15 (2.31)
	Weighted (PM/RM)	5.54 (2.26)	4.74 (2.36)	5.08 (2.60)
N=25	Forming intentions	8.96 (1.84)	8.80 (2.14)	9.36 (1.75)
	On time (PM)	5.32 (2.14)	4.20 (2.29)	5.12 (2.44)
	On time (PM/RM)	4.80 (2.27)	3.80 (2.42)	4,40 (2.50)
	Non omissions (PM)	7.32 (2.10)	6.28 (1.84)	7.24 (2.01)
	Non omissions (PM/RM)	6.36 (2.36)	5.28 (2.26)	6.00 (2.60)
	Weighted (PM)	6.54 (1.96)	5.48 (1.85)	6.49 (2.12)
	Weighted (PM/RM)	5.78 (2.24)	4.69 (2.18)	5.46 (2.47)

6.3.3.2 ***Random factors***

Random intercepts were included in the statistical model for both subjects and for PM tasks. This means that individual differences between subjects, as well as differences in scores for the different PM tasks are controlled for when calculating the effect of sound condition on task performance. Table 6-7 reports the variation in the different outcomes between individuals (subject) and PM tasks. All variances emerged to be significant. The largest variation for items occurred in the weighted scores and the non-omission scores.

Table 6-7 Variation estimates for the random intercepts.

	Outcome	Random effect	Est.	Std. error	Z	Sig.	95% C. I.	
							Lower	Upper
N=28	Forming intentions	Subject	0.542	0.208	2.603	0.009	0.255	1.151
		Item	1.039	0.313	3.321	0.001	0.576	1.875
	On time (PM)	Subject	0.564	0.200	2.822	0.005	0.282	1.130
		Item	0.664	0.218	3.045	0.002	0.349	1.264
	On time (PM/RM)	Subject	0.590	0.208	2.832	0.005	0.295	1.178
		Item	0.493	0.174	2.829	0.005	0.247	0.986
	Non omissions (PM)	Subject	0.416	0.157	2.659	0.008	0.199	0.870
		Item	1.118	0.331	3.377	0.001	0.626	1.997
	Non omissions (PM/RM)	Subject	0.525	0.187	2.808	0.005	0.261	1.056
		Item	0.689	0.220	3.126	0.002	0.368	1.289
	Weighted (PM)	Subject	0.018	0.006	2.939	0.003	0.009	0.035
		Item	0.035	0.010	3.598	0.000	0.020	0.061
	Weighted (PM/RM)	Subject	0.021	0.007	2.998	0.003	0.011	0.041
		Item	0.024	0.007	3.321	0.001	0.013	0.043
N=25	Forming intentions	Subject	0.555	0.225	2.463	0.014	0.251	1.230
		Subject	1.013	0.314	3.223	0.001	0.552	1.861
	On time (PM)	Item	0.518	0.196	2.637	0.008	0.246	1.089
		Subject	0.711	0.236	3.019	0.003	0.372	1.361
	On time (PM/RM)	Item	0.578	0.216	2.673	0.008	0.278	1.203
		Subject	0.523	0.188	2.788	0.005	0.259	1.056
	Non omissions (PM)	Item	0.287	0.126	2.278	0.023	0.121	0.678
		Subject	1.101	0.331	3.325	0.001	0.611	1.985
	Non omissions (PM/RM)	Item	0.447	0.173	2.586	0.010	0.209	0.953
		Subject	0.688	0.225	3.064	0.002	0.363	1.304
	Weighted (PM)	Item	0.014	0.005	2.632	0.008	0.007	0.030
		Subject	0.037	0.010	3.560	0.000	0.021	0.064
	Weighted (PM/RM)	Item	0.020	0.007	2.775	0.006	0.010	0.040
			0.025	0.008	3.276	0.001	0.014	0.046

6.3.3.3 *Effect of trial number*

Table 6-8 presents the F-test results for the effect of trial number of the individual GLMM models for each outcome of interest. None of the differences in scores between trials emerged to be significant when taking into account only 25 participants. Including all participants, however, the differences in scores between the three trials were significant for the non-omission PM score, the non-omission PM/RM score and the weighted PM score.

Post-hoc pairwise comparisons for these three outcomes revealed that, holding all other effects constant, the odds of non-omission (PM) increased by 44% in the second trial compared to the first trial, and by 54% in the third trial compared to the first (N=28). The odds of non-omission (PM/RM) increased by 36% in the second trial compared to the first trial and by 51% in the third trial compared to the first (N=28). The estimated marginal means of weighted scores (PM) are, per PM task, 0.457 (S.E. = 0.046) in the first trial, 0.506 (S.E. = 0.047) in the second trial and 0.535 (S.E. = 0.046) in the third trial. The effect of trial was not significant for all measures and lost its significance (at the $\alpha = 0.05$ level, not at $\alpha = 0.1$) after the exclusion of three participants.

Table 6-8 F-test results for the fixed effect of trial number, holding all other effects constant.

N/df	Outcome	F	Sig.
N=28, df1 =2, df2=1003	Forming intentions	0.314	0.730
	On time (PM)	1.538	0.215
	On time (PM/RM)	1.564	0.210
	Non omissions (PM)	3.335	0.036*
	Non omissions (PM/RM)	3.042	0.048*
	Weighted (PM)	3.168	0.043*
	Weighted (PM/RM)	2.665	0.070
N=25, df1 =2, df2=895	Forming intentions	0.166	0.847
	On time (PM)	1.565	0.210
	On time (PM/RM)	1.451	0.235
	Non omissions (PM)	2.287	0.102
	Non omissions (PM/RM)	2.926	0.054
	Weighted (PM)	2.357	0.095
	Weighted (PM/RM)	2.502	0.083

6.3.3.4 *Effect of sound condition*

Table 6-9 presents the F-test results for the effect of sound condition of the individual GLMM an LMM models. None of the differences in scores between sound conditions emerged to be significant when taking into account all 28 participants. After the exclusion of three participants, however, the differences in scores between the three sound conditions were significant for the on-time PM score, the non-omission PM score, the non-omission PM/RM score and the weighted scores for both PM, and PM/RM.

Table 6-9 F-test results for the fixed effect of sound condition, holding all other effects constant.

N/df	Outcome	F	Sig.
	Forming intentions	0.790	0.454
	On time (PM)	2.599	0.075
	On time (PM/RM)	1.974	0.139
N=28, df1 =2, df2=1003	Non omissions (PM)	1.708	0.182
	Non omissions (PM/RM)	2.156	0.116
	Weighted (PM)	2.774	0.063
	Weighted (PM/RM)	2.634	0.072
	Forming intentions	1.178	0.308
	On time (PM)	3.587	0.028*
	On time (PM/RM)	2.696	0.068
N=25, df1 =2, df2=895	Non omissions (PM)	3.556	0.029*
	Non omissions (PM/RM)	3.324	0.036*
	Weighted (PM)	4.943	0.007*
	Weighted (PM/RM)	4.208	0.015*

Table 6-10 shows the GLMM results of the post-hoc pairwise comparisons of scores in the different sound conditions, including odds ratios. The post-hoc pairwise comparisons of the LMM on the weighted scores are presented in Table 6-11. Holding all other effects constant, the odds of retrieving an intention on time (PM) increased by 59% in the ambient condition compared to the speech/absorbing condition (N=25). The odds of non-omission (PM) increased by 55% in the ambient condition compared to the speech/absorbing condition (N=25). The odds of non-omission (PM) in the speech/absorbing condition decreased by 35% compared to the speech/reverberant condition (N=25). Finally, the odds of non-omission (PM/RM) increased by 57% in the ambient condition compared to the speech/absorbing condition (N=25).

Significant increases of the weighted PM score, and the weighted PM/RM score were seen in the ambient condition compared to the speech/absorbing condition. The estimated marginal means (the mean response in a specific condition, adjusted for individual differences and the effect of PM task) of weighted scores (PM) are, per PM task, 0.545 (S.E. = 0.46) in the ambient condition, 0.453 (S.E. = 0.046) in the speech/absorbing condition and 0.544 (S.E. = 0.046) in the speech/reverberant condition (N=25). The estimated marginal means of weighted scores (PM/RM) are, per PM task, 0.481 (S.E. = 0.045) in the ambient condition, 0.386 (S.E. = 0.046) in the speech/absorbing condition and 0.460 (S.E. = 0.046) in the speech/reverberant condition (N=25).

Table 6-10 Post-hoc pairwise comparisons on the effect of sound condition (GLMM). Each comparison represents a test of participants' performance in one sound condition against another sound condition. The contrast estimate (log odds), standard error, *t*-value and Bonferroni corrected *p*-values are provided, as well as the 95% confidence intervals and the odds ratio which is calculated by exponentiating the contrast estimates.

Out-come	N / df	Post-hoc pairwise contrasts	Est.	Std. Error	t	p	95% C.I.		Odds ratio
							Lower	Upper	
Formed intentions	N = 28, df = 1003	Amb. vs S/A	0.01	0.20	0.07	0.94	-0.38	0.41	1.01
		Amb. vs S/R	-0.22	0.20	-1.08	0.80	-0.69	0.26	0.81
		S/A vs S/R	-0.23	0.21	-1.11	0.80	-0.73	0.27	0.79
	N = 25, df = 895	Amb. vs S/A	0.10	0.21	0.49	0.63	-0.31	0.51	1.11
		Amb. vs S/R	-0.23	0.22	-1.05	0.59	-0.71	0.26	0.80
		S/A vs S/R	-0.33	0.22	-1.51	0.40	-0.85	0.20	0.72
On time (PM)	N=28, df = 1003	Amb. vs S/A	0.40	0.18	2.26	0.07	-0.02	0.82	1.49
		Amb. vs S/R	0.14	0.17	0.83	0.41	-0.20	0.48	1.15
		S/A vs S/R	-0.25	0.18	-1.42	0.31	-0.65	0.15	0.78
	N = 25, df = 895	Amb. vs S/A	0.47	0.18	2.52	0.04*	0.02	0.91	1.59
		Amb. vs S/R	0.07	0.18	0.39	0.70	-0.29	0.43	1.07
		S/A vs S/R	-0.39	0.19	-2.09	0.07	-0.82	0.03	0.67
On time (PM/RM)	N = 28, df = 1003	Amb. vs S/A	0.35	0.18	1.97	0.15	-0.08	0.77	1.42
		Amb. vs S/R	0.20	0.17	1.15	0.50	-0.19	0.59	1.22
		S/A vs S/R	-0.15	0.18	-0.82	0.50	-0.52	0.22	0.86
	N = 25, df = 895	Amb. vs S/A	0.43	0.19	2.30	0.06	-0.02	0.87	1.53
		Amb. vs S/R	0.15	0.18	0.80	0.42	-0.21	0.51	1.16
		S/A vs S/R	-0.28	0.19	-1.47	0.28	-0.71	0.15	0.75
Non-omissions (PM)	N = 28, df = 1003	Amb. vs S/A	0.32	0.18	1.78	0.23	-0.11	0.74	1.37
		Amb. vs S/R	0.08	0.18	0.43	0.67	-0.27	0.42	1.08
		S/A vs S/R	-0.24	0.18	-1.33	0.37	-0.64	0.16	0.79
	N = 25, df = 895	Amb. vs S/A	0.44	0.19	2.36	0.05*	-0.01	0.89	1.55
		Amb. vs S/R	0.01	0.19	0.07	0.95	-0.36	0.38	1.01
		S/A vs S/R	-0.43	0.19	-2.25	0.05*	-0.86	0.01	0.65
Non Omissions (PM/RM)	N = 28, df = 1003	Amb. vs S/A	0.35	0.17	2.05	0.12	-0.06	0.76	1.42
		Amb. vs S/R	0.22	0.17	1.27	0.41	-0.17	0.60	1.24
		S/A vs S/R	-0.14	0.17	-0.79	0.43	-0.48	0.20	0.87
	N = 25, df = 895	Amb. vs S/A	0.45	0.18	2.48	0.04*	0.02	0.88	1.57
		Amb. vs S/R	0.10	0.18	0.58	0.56	-0.25	0.46	1.11
		S/A vs S/R	-0.34	0.18	-1.87	0.12	-0.76	0.07	0.71

Table 6-11 Post-hoc pairwise comparisons of the effect of sound condition (LMM). Each comparison represents a test of participants' performance in one sound condition against another sound condition. The contrast estimate, standard error, *t*-value and Bonferroni corrected *p*-values are provided, as well as the 95% confidence intervals.

Outcome	N/df	Post-hoc pairwise contrasts	Contrast estimate	Std. Error	t	p	95% C.I.	
							Lower	Upper
Weighted (PM)	N = 28, df = 941	Ambient vs S/A	0.069	0.031	2.207	0.083	-0.006	0.144
	N = 28, df = 942	Ambient vs S/R	0.11	0.031	0.353	0.724	-0.050	0.072
	N = 28, f = 943	S/A vs S/R	-0.058	0.032	-1.842	0.132	-0.129	0.013
	N = 25, df = 837	Ambient vs S/A	0.092	0.033	2.764	0.017*	0.012	0.171
	N = 25, df = 841	Ambient vs S/R	0.001	0.033	0.016	0.987	-0.065	0.066
	N = 25, df = 844	S/A vs S/R	-0.091	0.034	-2.694	0.017*	-0.169	-0.013
Weighted (PM/RM)	N = 28, df = 942	Ambient vs S/A	0.075	0.032	2.294	0.066	-0.003	0.152
	N = 28, df = 943	Ambient vs S/R	0.038	0.032	1.172	0.483	-0.034	0.110
	N = 28, df = 944	S/A vs S/R	-0.037	0.033	-1.125	0.483	-0.109	0.036
	N = 25, df = 838	Ambient vs S/A	0.096	0.034	2.780	0.017*	0.013	0.178
	N = 25, df = 843	Ambient vs S/R	0.021	0.034	0.612	0.541	-0.047	0.089
	N = 25, df = 847	S/A vs S/R	-0.074	0.035	-2.126	0.068	-0.153	0.004

6.3.4 Perceived disturbance and effect on task performance

Figure 6-11 shows the participants' ratings on the perceived disturbance due to the sound environment and the perceived effect of the sound environment on their reading performance while reading the EMR.

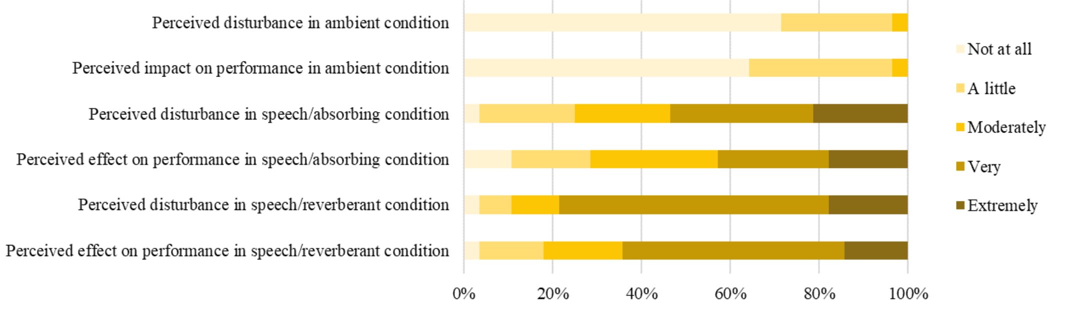

Figure 6-11 Subjective ratings of sound conditions.

Friedman tests were used to determine whether there were differences in perceived disturbance and perceived effects on performance as a result of sound condition. Perceived disturbance was significantly different for the different sound conditions, $\chi^2(2) = 45.575$ $p < .001$. Wilcoxon tests with a Bonferroni correction applied were used to follow up this finding, resulting in a significance level set at $p < 0.017$. Statistically significant differences emerged in perceived disturbance during the ambient sound condition (Mdn = 1) compared to both the absorbing sound condition (Mdn = 4) ($Z = -4.587$, $p < 0.01$) and the reverberant sound condition (Mdn = 4) ($Z = -4.617$, $p < 0.01$). No significant difference emerged between the absorbing and reverberant sound condition ($Z = -1.801$, $p = 0.072$). The perceived effect on performance was also significantly different for the different sound conditions, $\chi2(2) = 42.473$, $p < .001$. Post hoc analysis revealed statistically significant differences in perceived effect on performance during the ambient sound condition (Mdn = 1) compared to both the absorbing sound condition (Mdn = 3) ($Z = -4.260$, $p < 0.01$) and the reverberant sound condition (Mdn = 4) ($Z = -4.594$, $p < 0.01$). No significant difference emerged between the absorbing and reverberant sound condition ($Z = -1.767$, $p = 0.077$).

6.4 Discussion

The aim of this experiment was to measure whether the forming of intentions by nurses working in a hospital ward, and the retrieval of those intentions is influenced by the acoustic environment in which the intentions are formed, and whether realistic interventions, being removal of a sound source or room acoustic measures make a difference. A novel experimental task was used which was designed to resemble the complex task that nurses perform in a typical hospital ward. Because the experimental task was not used in the context of nursing before, an exploratory analysis was performed in which the effects of trial number and PM task were also explored.

6.4.1 **Findings**

6.4.1.1 ***Forming PM intentions***

In the current experiment, forming intentions was measured by logging the tasks that were recognized and verbalized by the participants while reading the EMR. While there was a slight, non-significant increase in verbalized intentions during the speech/reverberant condition, overall, the number of formed intentions was not significantly influenced by sound condition. The straightforward conclusion based on this result is that neither the presence of background speech, nor the amount of sound absorbing material in the simulated nurses' station affect the forming of intentions when reading the EMR. To be able to conclude this, however, it has to be certain that logging verbalized to-be-performed actions provides a robust measure of formed intentions.

6.4.1.2 ***Retrieving PM intentions***

Three outcome measures for the retrieval of PM intentions were defined. Regardless of the outcome measure, a main effect of sound condition emerged (N=25). Post-hoc comparisons revealed that performance was significantly lower in the speech/absorbing condition compared to the ambient condition. The average PM performance in the speech/reverberant condition was, for all measures, only slightly lower than in the ambient condition and therefore also better than in the speech/absorbing conditions. This difference in performance between the speech/absorbing and the speech/reverberant condition emerged to be significant for the non-omission score (PM) and the weighted score (PM) (N=25). While at a first glance, these results, indicating a lower performance when the speech intelligibility of background speech improves, are in line with a multitude of studies reporting results in the same direction, the magnitude of the effect, given the small sample size and small difference in STI is unexpected. Larger differences are found than would be expected, especially in comparison with the almost negligible differences in performance between the ambient condition and the speech/reverberant condition.

The calculated STI value for the source-receiver path in the reverberant condition is 0.61, the calculated STI in the absorbing condition is 0.78. A model by Hongisto et al. (2005), a sigmoidal curve predicting a task performance change based on the STI of background speech, shows a steep slope of decline in performance for STI values between 0.2 and 0.6, which then flattens out to an almost horizontal line. Both STI values that were used in the current experiment are within this 'flat range', which would predict an equally large performance decrement for both speech conditions compared to the ambient condition. Our results are even more out of sync with findings presented by Jahncke, et al. (2013) which imply that a maximum performance decrease is reached at a STI of 0.35.

6.4.1.3 ***Contributing factors***

Three important aspects have to be kept in mind when comparing our findings to those of others. The first is the task-dependency of a sound effect, which could be a possible explanation for our results, indicating that encoding PM intentions is very sensitive to the presence of background speech. The second is our small sample size, reflected in the wide confidence intervals of the results, combined with a complex task. More robust findings could be achieved in a sequence of further studies. Such studies could be performed with the aim of validating the experimental task. Here, different sound conditions with a more specific focus on the intelligibility of speech could be used.

The third aspect that potentially plays an important role is the content of the background speech that was used. By content, we refer to the topic of the conversations, in our case discussions about patients and personal life. While irrelevant to the task, these conversations could be regarded as relevant (interesting) from the perspective of nursing in general. In this view, relevant content is not the same as meaningfulness, which refers to whether the speech 'has some meaning' to the listener. Examples of meaningless speech are backward played speech or speech in a language unknown to the listener. In most studies on auditory distraction, attentional capture is regarded as 'aspecific', meaning that the listener's expectation about the sound environment, which is based on the sound environment in the recent past, is violated. This means that there is no property of the sound itself that is drawing away a subject's attention (Röer, Bell, & Buchner, 2014). In contrast, specific attentional capture occurs when the content of the sound is speaking to the interest of an involuntary listener (Röer et al., 2013). Given that a professionals' mindset, interests and knowledge are, to a certain extent, known, it could be possible to predict which sound events would attract their - involuntary- attention as a result of its particular content. The background speech employed in the current experiment, may have captured the participants' attention due to its specific content (topic). If so, this emphasizes the need to carefully study the content of background conversations in work environments to assess their effects on performance. Furthermore, it supports the theory that speech intelligibility is an important aspect in minimizing performance decrements as a result of background speech.

6.4.1.4 ***Outcome measures***

In the analysis of results, PM performance was measured by different outcomes. PM scores were based on the prospective element of the task only, discarding the retrospective content of the tasks. PM/RM scores were based on both the prospective and retrospective content. Additionally, a distinction was made between on-time scores, non-omission scores and weighted scores.

The effects of sound condition in the on-time (PM) score and the non-omission (PM) score were moderately larger than the effects in the weighted (PM) scores. Furthermore, the difference in scores between the ambient and the speech/absorbing condition was more pronounced in the PM scores compared to the PM/RM scores. The latter hints at the idea that encoding PM is more sensitive to intelligible background speech than RM. Another difference between the outcome measures was found taking a closer look at the post-hoc pairwise comparisons between the ambient and the speech/reverberant condition. While never significant, the difference in scores between the ambient and the speech/reverberant increases for the PM/RM outcomes compared to the PM outcomes, which is the opposite direction of the difference between ambient and speech/absorbing. This again suggests that the intelligibility of to-be-ignored background speech is more important for PM than for RM. While the slight differences described above cannot form the base of firm conclusions, they do implicate the need for further research on the effect of speech intelligibility of background speech on the encoding of PM.

The objective results are not in line with the subjective results of our study. Whereas the speech/absorbing condition led to a performance impairment compared to the speech/reverberant condition, both conditions were perceived as equally disturbing. In fact, although not significant, the speech reverberant condition was perceived to have a slightly larger effect on performance than the speech/absorbing condition. Perceived disturbance and perceived effects on performance may greatly impact job satisfaction, tiredness or alertness and should therefore not be ignored.

6.4.2 **Virtual Shift**

A board game called Virtual Week was transformed into Virtual Shift with the purpose of measuring PM performance of nurses. While Virtual Week has been validated, the validation of Virtual Shift, which has a different time scale and contains different tasks that were to be interpreted from a simulated EMR, was limited to face, content and ecological validation by two professional nurses. Key aspects that need further exploration and validation are the number of included tasks, the content of the excluded tasks and the difficulty to distinguish between to be performed tasks and excluded tasks. Furthermore, the content of events in the board game, the decisions that have to be made based on these events and the cues they can provide have to be explored further.

In the current experiment, twelve tasks for three patients were included in each trial. Task difficulty has been shown to be an important predictor for the effect of sound on the performance of that task (Halin et al., 2014; Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Sörqvist & Marsh, 2015). Increased difficulty can increase task engagement and acts as a shield against distraction. In the case of PM, the task load, meaning the number of PM tasks, could be a possible confounder. This could also be the case for the complexity of the PM tasks' content.

The main reason not to include 20 PM tasks in the current experiment was that in practice, nurses use reminders, such as written notes, and are able to access a computer during the shift. Additionally, in the typical ward environment, besides planned reminders, there are many cues that help to correctly execute a PM intention. These cues can be visual, such as seeing an almost empty infusion pump, or auditory, such as the hissing sound of a nebulizer that reminds a nurse to nebulize a patient. While in the current study, we aimed to simulate such contextual cues, it was expected that a task load of 20 PM tasks would be too high. The experimental task, Virtual Shift, could be a useful tool to further explore the effect of PM load on nurses' PM performance in different sound conditions.

Contextual cues were simulated by showing a picture including some admission details of each patient for the events that regard that patient. Furthermore, the descriptions of the events were tailored to the information about that patient in the EMR to improve an engagement in the situation. The extent to which the descriptions in each patient scenario provide cues or hints to perform PM intentions should be carefully looked into in further development of Virtual Shift, to ensure equal difficulty between the patient scenarios.

Another factor that influences the complexity of the experimental task are the decisions that were to be made when an event popped up. It was aimed to find a balance between very non-trivial decisions and more complex decisions in each scenario. An example of a simple decision is whether to close the door to a patient's room or not. An example of a more complex decision is whether or not to adjust pain medication and in which direction. When more complex decisions have to be made, it might increase the chance of intentions being forgotten, regardless of the sound environment the intentions were formed in. In the further development of Virtual Shift, scenarios with varying levels of complexities could be explored.

In the current experiment, intentions were only formed while reading the EMR and not during the board game, which contradicts reality. Furthermore, the sound conditions were only resembling the actual environment during this first phase. While the current design offers the possibility to analyze the effect of the sound environment in the nurses' station, the effect of forming intentions during the board game should be explored further. The event descriptions that pop-up when passing or landing on an event square provide the opportunity to introduce additional PM tasks during the game. Finally, the influence of the sound environment, or another external factor, during the retrieval phase of the board game could be explored further.

The simulated EMR that was developed for the current experiment was based on screenshots from the collaborating hospital's EMR. This improved the resemblance of the task to reality but reduces the reproducibility of the first phase of the experiment and the content of the included PM tasks in the board game.

6.5 **Conclusions**

Our first hypothesis, the sound environment in a nurses' station influences the forming of prospective memory intentions, is not supported by the results of the experiment. Our results do support the hypothesis that the encoding of PM intentions is influenced by the sound environment and deserves further research attention. Here, the role of speech intelligibility as a predictor should be further explored. Based on our findings, we conclude that the presence of background speech with a high intelligibility, as a result from a low reverberation time, during the forming of intentions, leads to a significant decrease in PM performance compared to a situation without speech. Furthermore, for two outcome measures, increasing the reverberation time in the presence of background speech improved PM performance. Due to the exploratory nature of the experiment, and our specific focus on PM, our findings must be interpreted with caution. The sound environment can have a different influence on other tasks and the subjective ratings of disturbance and perceived effects on performance should not be ignored.

Overall, Virtual Shift has the potential to measure PM performance in the dedicated setting of nursing. The complex task that was used, combined with realistic sound conditions, and realistic differences between sound conditions make our results very relevant for this specific setting, but the small sample size gives reason for caution in generalizing and interpreting results. Furthermore, Virtual Shift offers possibilities for a range of other research queries unrelated to the sound environment, such as education, PM training, and planning of care.

The results of this study indicate that intelligible background speech while reading the EMR to plan care activities, has a detrimental effect on the correct retrieval of formed intentions. In a hospital, but also in other care, or non-care related settings in which the correct retrieval of intentions is vital, distraction by background speech should be prevented. It is the responsibility of hospital management and architects to design workspaces that accommodate all necessary tasks. It is the responsibility of nurses to make use of these spaces.

6

7

General discussion

7 General discussion

In the past chapters, our research on the influence of the sound environment on nurses' cognitive performance has been presented with the aim of providing insights that are meaningful from an applied perspective. To that end, both sound conditions and experimental tasks had to be representative of the work environment of interest. This required the integration of the perspectives, knowledge and methods from different disciplines. Very little knowledge was available on the influence of the sound environment on the cognitive work of nurses. Furthermore, the results of a literature review indicated that empirically studying the effects of the sound environment on human performance is generally performed in laboratory settings that do not sufficiently represent realistic work settings. These early findings left us with an empty canvas, and the opportunity to pursue a secondary goal: to employ an exploratory approach that could guide future studies on the influence of the sound environment on task performance.

In this final chapter, we will substantiate and reflect upon our work from two separate perspectives. First, in section 7.1, the exploratory approach that was used is reflected upon. Here, attention will be paid to the question to what extent the used approach can be considered a generic approach beyond the domain of nursing. Second, section 7.2, is a discussion of the main findings of this thesis. A summary of each chapter's main contributions is presented in section 7.2.1. In sections 7.2.2 and 7.2.3 these findings will be considered in light of existing knowledge and their practical implications. The overall strengths and limitations of the thesis are discussed in section 7.3. Finally, to conclude this chapter, directions for future research are presented in section 7.4 followed by conclude our conclude ng remarks in section 7.5.

7.1 A generic approach to studying the effect of the sound environment on task performance

Our goal was to gain insight in the sound environment, the task and their interaction at a workplace, and to use this insight in the design of an ecologically valid experiment. There was no expected outcome, no hypothesis, and there was no predefined shape or form in which the data we set to collect had to come. As mentioned earlier, the canvas was blank.

This first part of our approach, an initial open-minded observation turned out to be a key factor in determining the study parameters and method of the final data collection and therefore the final outcomes. Not having a specific focus helped to get an unbiased view on nursing characteristics, the sound environment at the ward and the task-sound interaction. We are convinced that this lack of focus has contributed to the identification of the themes, prospective memory and distractions that were central in the final data collection. These themes were further explored by studying the available literature, the second step in our approach. In this second step, the importance of the themes was substantiated and questions regarding the themes were formulated.

In the third part of our approach, the focused observation study, we aimed to answer these questions. The collected data led to insights in the number of PM intentions that a nurse has to remember during one shift, the execution of these intentions (in time, delayed or omitted) and the reason for these omissions. Furthermore, the content of formed, retrieved and omitted intentions could be analyzed. These insights, presented in **Chapters 4 and 5** of this thesis are not only valuable in the context of our approach but, as will be elaborated in the next sections, also in a broader context. In the fourth and final part of our approach, findings from the observation study were integrated in an experimental design, representative of the nurses' work and sound environment.

The combination of methods that were used in the third part of our approach, observation, thinking aloud (TA), audio recordings and personalized questionnaires, was tailored to nurses and the environment they are working in. A different setting could ask for a different combination of methods, based on the study parameters which are deemed relevant for that specific environment. The same implication holds for the experimental design, which was developed based on the results of the observations. By abstracting from these specific methodological elements, an overall approach can be distilled which is roughly schematized in Figure 7-1. It shows the generic steps that were taken which could, with the right permissions, be performed at any workplace.

The components in the separate steps show a strong link with the conceptual model on the effect of the sound environment on task performance in Figure 2-3. By following this approach we are taking into account the characteristics of the target group, gain insight in the complex tasks they perform and the sound environment that is representative for their work environment. The controlled laboratory experiment, based on findings from the observation, allows studying the influence of realistic interventions regarding the sound environment. This can be done, for example, by varying room acoustic parameters, or the presence and/or behavior of sound sources.

In the combination of methods that were used, both job observation and audio recordings are considered an essential part of our approach. Audio recordings are required because measuring sound levels alone does not provide enough information about the sound environment and the possibility for offline analysis increases the validity of the study. Observation provides the visual input that is directly translated to a log and aids the offline analysis of the audio. Due to privacy issues, permission to make audio recordings can be a challenge in any environment.

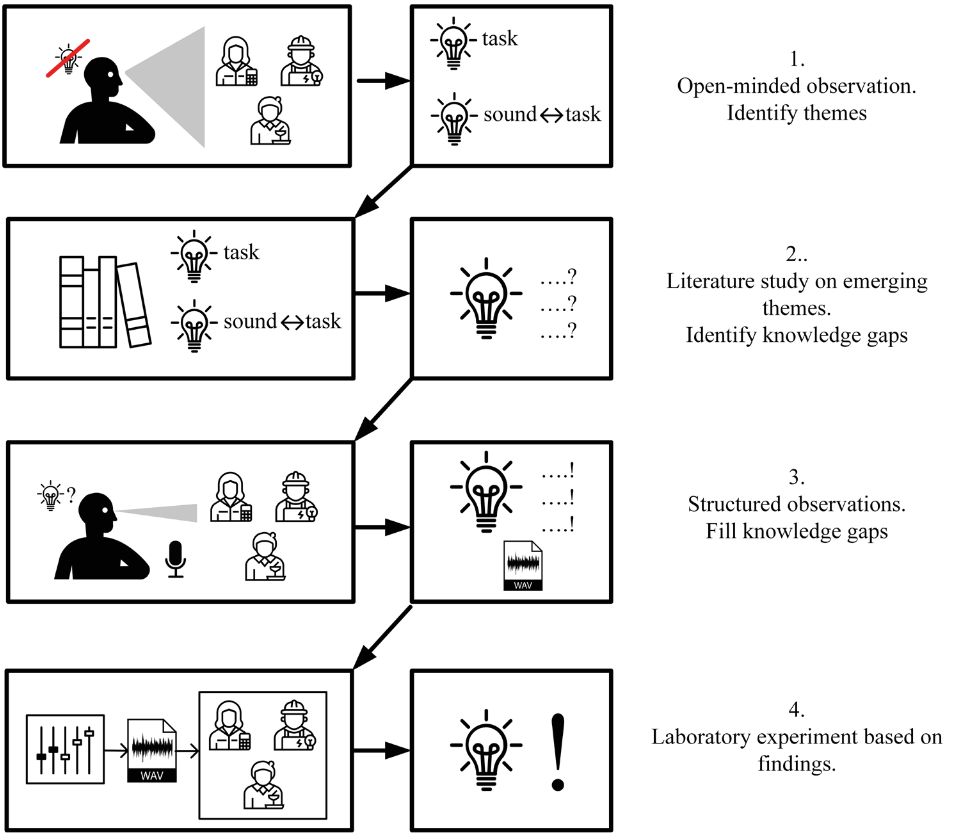

Figure 7-1 Schematization of our applied, explorative approach

7.2 Findings presented in this thesis

7.2.1 Main findings

Our project started with a review of the literature on effects of sound on cognitive tasks with a narrow scope: including only studies of which the results allow a direct translation to effects of realistic room acoustic interventions on task performance. Only 12 papers were selected, describing the results of 24 experiments. The majority of these experiments, 16 out of 24, used experimental tasks designed to measure an ability rather than a complex task, rendering them unsuitable for translation to applied settings. **Claims regarding the influence of room acoustics on task performance in an applied setting can hardly be made based on existing knowledge**. A conceptual model was suggested which guided our further exploration. This model, depicted in Figure 2-3, shows that the sound environment can be influenced, either through controlling the sound sources and their behavior, or through controlling room acoustics. Three important factors were included that have to be taken into account when studying the effect of the indoor sound environment on human performance. These are the task characteristics, personal factors and the role of sound for a task (task-sound interaction). The model also includes other environmental factors. Therefore, to better understand the effect of the sound environment on the performance of nurses, it was necessary to gain insight in the actual sound environment at their workplace, the tasks they performed and the task-sound interaction.

An observation study was conducted in two nursing wards of a Dutch hospital, focusing on the combinations of sound environments and tasks, distractions and the forming and retrieving of prospective memory (PM) intentions. In our simultaneous analysis of the sound environment and nursing tasks, **a conflict between the need for situational awareness and task concentration** was observed. Another result of the observation study was the number of observed distractions that could be linked to the sound environment. On average, 12 distractions were observed each hour which corresponds to **being distracted every 5 minutes**. This number does not include any distractions which were invisible to the observer. The majority of observed distractions were intentional, meaning the source of the distraction intended to capture the observed nurses' attention. **The main source of intentional distractions was speech from colleagues**, often providing relevant information for the nurse. 18% of the observed distractions were unintentional. **The main source of unintentional distractions was background speech**, of which 31% were considered to be potentially useful. Reading electronic medical records and receiving the verbal change of shift report, both with the aim of planning patient care were, without exception, performed while being exposed to intelligible background conversations. These were identified as **critical combinations of task and sound environment.**

Missed nursing care, discussed in **Chapter 5**, has the potential of influencing patient outcomes, patient satisfaction and job satisfaction. The results of our observation study, complemented by questionnaires, revealed that **over 40% of delayed or omitted activities were caused by prospective memory (PM) failures** according to nurses' self-report**.** In our analysis of formed and retrieved intentions, a new type of PM task was proposed, that differed from time-based, event-based and activity-based PM tasks as its window of opportunity for correct execution is broader. It turns out that these **'free' PM tasks are more likely to be omitted.** Moreover, in line with existing literature, we found **perceived task priority to be a predictor of PM failures.**

The findings of our observation study were used to **develop a novel experimental task** that combines reading patient files in a simulated electronic medical record (EMR) with an adapted version of the validated task 'Virtual Week'. The new experimental task was called Virtual Shift. Virtual Shift was performed by nurses under different, realistic, sound conditions. The results indicate that the **sound conditions did not influence the number of formed intentions.** The three sound conditions that were used were an ambient condition without background speech, a condition with background speech in a room with a sound absorbing ceiling and walls, and a condition with background speech in a room with a sound reflecting ceiling and walls. The results indicated a significantly worse PM performance in the condition with speech in a sound absorbing room. More specifically, **the odds of retrieving a PM intention on time increased by 59% in the ambient condition compared to the speech/absorbing condition.**

7.2.2 Implications of the findings

7.2.2.1 *Design decisions in the context of a healing environment*

In the first chapter of this thesis, it was stated that the sound environment influences us, but that we can also influence the sound environment. Acoustic regulations and recommendations are possible ways to achieve this. Regulations and guidelines regarding hospital acoustics come in many shapes and forms. The most basic form in European countries can be found in national building regulations that, depending on the country, set limits regarding airborne and impact sound insulation between rooms, façade sound insulation, service equipment noise and room acoustics (Rasmussen, 2018). These regulations are not in place to create optimal healing environments, but rather to ensure a building quality that does not negatively impact the occupants' health and safety (Imrie, 2007). Additionally, standards exist that classify the acoustic quality of buildings, including hospitals, based on the parameters described above (Rasmussen, 2018). Here, recommendations regarding room acoustics are typically only specified for patient rooms, but not specifically for staff areas or corridors. Another increasingly well-known tool is the Well Building standard, launched in 2014. The Well Building standard is a rating system for homes and offices based on features of the built environment that impact human health and well-being. Sound is incorporated in the standard through acoustical comfort parameters. According to the website of the International Well Building Institute, pilot programs to apply the Well Building standard to different space types, including healthcare, are in development (International Well Building Institute, 2017). The work in this thesis adds to the knowledge on which future guidelines and recommendations can be based, by approaching the hospital sound environment from the perspective of nurses. For them, the hospital is their workplace and the sound environment is expected to influence their task performance.

In the early stages of this project, based on our review of the literature, we concluded that claims regarding the influence of room acoustics on task performance in an applied setting can hardly be made based on existing knowledge (**Chapter 2**). One reason for this is the lack of studies comparing the effect of realistic sound conditions and realistic interventions on task performance. This lack was addressed in the experiment described in **Chapter 6** of this thesis. The speech that was used in the experiment, conversations about patients between two nurses, was based on actual conversations that were recorded in a nurses' station during the observations described in **Chapter 3**. The results presented in **Chapter 6** indicate a performance decline as a result of intelligible background speech (STI= 0.78) in an acoustically treated room compared to a situation without speech, when the outcome of interest was the retrieval of PM intentions. A performance decline was also observed in the case of background speech in an acoustically treated room compared to background speech in a reverberant room, although not statistically significant. A dangerous interpretation of these results would be to increase reverberation times in nurses' stations in order to reduce the speech intelligibility of background speech. This interpretation is dangerous for two reasons. First, because such an intervention would also decrease the speech intelligibility for those who are having the conversation. As shown in **Chapters 4 and 5**, these conversations include transferring vital information about patients. Second, because increasing reverberation times does not only affect speech intelligibility. It also affects the overall sound level, which, as studies have shown, is not directly affecting task performance but might lead to higher stress levels (in the long term), fatigue, increased subjective disturbance, annoyance and health issues (Evans & Johnson, 2000; Leather et al., 2003; Morrison et al., 2003). This means that the development of room acoustic recommendations faces both the complexity of possible conflicts between outcomes of interest and the complexity of multiple occupant groups who may be performing different activities. In this thesis, only one outcome and one user group were addressed. Careful consideration of other user groups and other outcomes is necessary in the context of making design decisions.

As the conceptual model in Figure 2-3 suggests, the sound environment in an indoor workplace is determined by the sound sources that are present, their behavior over time and the acoustic properties of the room. This means that building acoustics alone, including the noise produced by service equipment, cannot be regarded as a sufficient predictor of the sound environment. Besides building acoustics, there are several other disciplines involved in the creation of a 'healing sound environment'. An architects' layout of a ward influences which sounds are produced where, and the management of alarms and other (medical) equipment greatly influences the sound sources that are present in a ward. Furthermore, as the behavior of occupants plays an important role in the sound environments, management should not be overlooked. In the case of a hospital ward, it is the local management that determines visitors' regulations, staffing and ways of working. Lastly, it is the responsibility of each individual occupant to consider the impact of their behavior on the sound environment.

In **Chapter 4** of this thesis, critical combinations of task and sound environment were identified. Those were focal tasks, such as reading and planning care, receiving (or giving) a verbal transfer and medication preparation and checking. In the case of reading and planning care, it was seen that this was often performed in an enclosed space while being exposed to intelligible background conversations about ‘relevant’ topics. Medication preparation and checking were seen as critical mainly when it was performed in the ward corridor. Here, even though the nurses wore ‘do not disturb vests’, the nurses were occasionally distracted by either background speech or directed speech. Based on these findings, it was suggested in **Chapter 4** to extend the concept of activity-based-workplaces to hospital wards.

Activity-based-working, is based on the idea that different tasks require different environments (Appel-Meulenbroek, Groenen, & Janssen, 2011; Brand, 2017). For example, incorporating small bays in the corridor, shielded from the activity and dedicated for concentrated work could potentially reduce distraction during medication preparation and checking. Such a concept would have to be explored further. In **Chapter 6**, the critical combination of reading and planning care in the presence of background speech was investigated. The results indicate that dedicated spaces for reading and planning care or important conversations could prevent task performance to be affected by background speech. In a field study by a Dutch architect, nine recently built hospitals in the Netherlands were analyzed. It was concluded that different rooms for concentrated work, verbal transfers and informal breaks were generally not present in the wards. Typically, the staff area in a ward consisted of a central nurses’ station and one room/office for a doctor or the unit manager (Herweijer-van Gelder, 2016). Although no such evaluations were found for newly built hospitals in other countries, these findings indicate that there is room for improvement and innovation.

A precondition for activity-based-working to be successful, in offices at least, is proper training in how spaces should be used (Appel-Meulenbroek et al., 2011). In the case of nursing, the general workflow and division of tasks may also have to change, as shielding oneself from all possible distractions is not always possible. Local management and individual willingness play an important part here.

Another example of the role of people in the sound environment was seen in **Chapter 4** of this thesis, where it was shown that nurses were most frequently distracted by speech, either intended (directed speech) or unintended (background speech). This finding shows that human behavior is an important aspect in the sound environment. Examples of staff education and awareness programs have been proven successful in reducing patient experiences of noise in a ward (Applebaum, Calo, & Neville, 2016; Richardson, Thompson, Coghill, Chambers, & Turnock, 2009). A logical next step, based on the findings in this thesis, would be to explore the potential of staff education on how their behavior (and the consequential sounds) affects colleagues.

In general, guidelines regarding the sound environment are developed from a single discipline, such as building acoustics, alarm management or staff management. Such guidelines rely mainly on the sound levels in patients’ rooms and treatment rooms that have to be kept to a minimum for the sleep quality and comfort of patients. The results presented in this thesis emphasize the need to employ a holistic approach in creating a suitable sound environment. Such an approach should be accounting for all factors influencing the sound environment. Our conclusions are in line with a report on the impact of the physical environment on healthcare workers by the Center for Health Design. Their final recommendations include to identify steps promoting cultural changes parallel to design changes to ensure effectiveness and acceptance for new innovations, to provide opportunities for spontaneous and planned interactions between staff through design, to conduct ergonomic evaluations of staff areas and to institute measures reducing noise stress among nurses through improving acoustic conditions in the nursing unit, education and awareness programs (Joseph, 2006).

7.2.2.2 *Insights regarding nurses' task performance*

The main aim of the project described in this thesis was to explore the effect of sound on nursing performance. As a consequence, a considerable share of the collected data and analyses regards the task of nurses in a hospital ward. Besides contributing to the main aim of this thesis, the results from these analyses are relevant for nursing practice as well.

Interruptions and distractions have been reported to be associated with medication errors (Prakash et al., 2014; Scott-Cawiezell et al., 2007; Westbrook, Woods, Rob, Dunsmuir, & Day, 2010). In **Chapter 4**, distractions and interruptions during different activities and in different locations were analyzed and reported. A novelty of the presented analysis was the distinction between intended and unintended distractions. It was found that while being busy with medication, nurses were, on average, intentionally distracted nine times per hour. By intentionally, it was meant that the source of the distraction intended to capture the nurses' attention. Here, one person's need to share information, or ask for attention, conflicted with the need to concentrate on a task for another person. Unintended distractions were observed five times per hour during this task. As judged by the author, a considerable share of these distractions contained potentially useful or even vital information. A theme that emerged based on these findings, was the conflict between the need for situational awareness and task concentration. This conflict between task focus and the need to be aware of one's surroundings was also recognized in an explorative study by Bower et al. (2018). Situational awareness (SA) can be defined by "the perception of the elements in the environment in a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Ensley, 1995). In the context of nursing, situational awareness is considered an important skill required to ensure patient safety (Fore & Sculli, 2013).

In our reading of the literature, no studies were found exploring this conflict between SA and task concentration. Studies were found in transportation research, addressing the impact of secondary tasks (such as working with in-vehicle information systems or mobile phones) on situational awareness. Their results indicate a decreased performance of the primary task (the one which requires SA) in the presence of a secondary tasks with increasing complexity (Blanco, Biever, Gallagher, & Dingus, 2006; Reimer, 2009). To the best of our knowledge, no studies have been reported addressing the impact of increased situational awareness on the performance of the secondary task. Based on the above, we ask ourselves whether SA and the mindset that is required for achieving SA, comes at a cost. If so, the workflow strategy that was used in the observed ward, sharing the responsibility for patients in pairs, could be further exploited. As suggested in **Chapter 4**, and further elaborated on in section 7.2.2, shared care for patients could offer the opportunity for a nurse to momentarily allow a mindset that blocks distractions while a colleague remains vigilant. Implementation of these strategies is dependent on the facilities that the ward environment offers, local management and the willingness of staff to adapt to different ways of working.

In this thesis, the conflict of SA and task concentration was not explored any further and it was not taken into account in the experiment presented in **Chapter 6**. It was implicitly assumed that at the start of the day shift, while reading the EPD, colleagues of the night shift would still be working and vigilant. However, participants were not explicitly informed that all background sounds could be ignored. The findings presented in **Chapter 4** may form the basis for developing and exploring strategies to deal with this conflict.

As suggested by this thesis' subtitle, one cognitive aspect of a hospital nurses' job, prospective memory (PM), received particular interest. This theme was identified in the analysis of the initial observations presented in **Chapter 3**, and was further explored in **Chapter 5**. Here it was concluded that over 40% of delayed and omitted activities were due to PM failures. Not executing the care activities that are planned to be executed for a patient constitutes an error of omission, or missed care.

Forgetting to execute an intended activity constitutes a prospective memory failure. In recent years literature on missed care has increased, as well as the literature on PM. The explicit link between the two concepts, however, was to our knowledge not studied before. Exploring this link can be seen as an important result of the explorative and interdisciplinary nature of this project.

Missed nursing care as a result of PM failures can be addressed from two perspectives. The first is internal, through interventions, such as training, with the aim of improving prospective memory. The novel experimental task presented in **Chapter 6**, Virtual Shift, is a potentially useful tool to train and improve nurses' PM. As described in **Chapter 6**, the task is adapted from the validated experimental task Virtual Week (Rendell & Craik, 2000). This task has been shown to be effective in improving PM in other target groups (Rose et al., 2015).

The second perspective to address PM failures is external. For example, the use of healthcare information technology, in the shape of electronic nursing care reminders, is considered to be effective (Piscotty & Kalisch, 2014). In the hospital in which the observations described in **Chapter 3**, and the experiment described in **Chapter 6** were conducted, most of the planned care activities were incorporated in a checklist that was part of the healthcare information system. This checklist was studied at the start of the shift (as replicated in the first phase of the experiment described in **Chapter 6**) and could be accessed on any computer during the shift. Relying on such a checklist requires discipline, however. Marking actions as 'done' before actually executing them is a potential risk. Furthermore, new intentions that are formed during the shift would have to be documented immediately. In the design of systems that provide electronic nursing care reminders, careful study of which reminders nurses find useful and which reminders result in the best quality outcomes is required (Piscotty, Kalisch, & Gracey□Thomas, 2015).

The problem of additional load that is introduced when using new technology, such as electronic nursing care reminders, is addressed in the field of peripheral interaction which explores the design of human-computer interaction that is able to be carried out in the periphery of users' attention (Bakker, van den Hoven, & Eggen, 2015). For example, inspired by ClassBeacons, a tool to visualize teachers' proximity to students in a class room (An et al., 2019), one could think of lights above patient rooms that by changing color or brightness indicate the time that has passed since a nurse has visited that patient or turned that patient. If such technologies could be implemented seamlessly and without any additional effort for the nurses, they have the potential to reduce missed care.

7.2.2.3 *Implications for prospective memory research*

PM tasks are generally categorized as either time-based, event-based or activity-based. This means that the window of opportunity for task execution is a specific timeframe, linked to an event or linked to an activity. In the analysis of intentions in **Chapter 5**, a fourth type of PM task was defined: a free PM task. PM tasks were categorized as 'free' when they had to be executed at some point during the nurses' shift, but there was no clear timeframe, event or activity to which task execution was linked. The results of the analysis suggested that these free PM tasks have a higher chance of being omitted. Considering the theory of PM, it could be argued whether the free PM task is really a PM task. According to McDaniel and Einstein (McDaniel & Einstein, 2007) one of the parameters of a PM task is a constrained window of opportunity. For example, my intention to create a vegetable garden can be considered fulfilled if I do it this afternoon, this spring or next spring. To be considered a PM task, the window of opportunity should be clearly defined. In the case of the free PM task, the window of opportunity could be constrained to the nurses' current shift, although some intentions, for example to clean out an email folder can also be considered to be fulfilled if they are performed later this week. If the window of opportunity is constrained to the shift, one could argue that the PM task is activity-based, with the shift being the activity. In this case, however, we argue that the definition of a free PM tasks helps to identify those tasks most likely to be forgotten.

In this thesis, PM and distractions were analyzed in two separate chapters. It has to be noted though, that here is a strong link between the two concepts. First, interruptions create new PM tasks (Dodhia & Dismukes, 2009). When an activity is halted in order to engage in another activity, it can be assumed that the implicit intention is formed of finishing the current activity after the interruption. In the logging of intentions in **Chapter 5**, this was taken into account. Second, distractions and interruptions may also create new PM tasks as a consequence of the information that is involved with the distraction. Besides the creation of PM tasks as a result of interruptions, both the effect of interruptions (Grundgeiger et al., 2008; Shum, Cross, Ford, & Ownsworth, 2008; Shum, Cahill, Hohaus, O'Gorman, & Chan, 2013) and distractions (Knight, Nicholls, & Titov, 2008) on PM are reported in literature.

The results of these studies suggest that PM performance is decreased by external interruptions and distractions. In the experiment in **Chapter 6**, the exposure to the potentially distracting background speech was limited to the phase in which intentions were formed. No distractions were included in the second phase of the experiment, nor were there any new intentions for PM tasks to be formed. A suggestion for future research is to explore the effect of interruptions and forming new intentions during task execution combined with the effects of a realistic sound environment on PM performance. An example of a study on the combined effects of interruptions and background speech on the performance of a writing task can be found in Keus van de Poll and Sörqvist (2016). Further development of the experimental task in **Chapter 6**, Virtual Shift, offers the potential of exploring these combined effects on PM.

In the further development of Virtual Shift, another factor that has to be carefully considered is the complexity of the task. This regards both the complexity of the individual PM tasks but also the complexity of the choices that have to be made regarding the events that occur. Furthermore, the information that these events contain, can also serve as a reminder or cue for the to be performed intentions. All these factors need further exploration.

7.3 Strengths and limitations of this thesis

7.3.1 The project

The main strength of our approach is the combination of field and experimental research which make our results meaningful from an applied perspective, while also resulting in valuable theoretical insights that provide a starting point for more fundamental studies. We have shown there is an effect of the sound environment on retrieving PM intentions in a very specific setting: nursing practice. Given the importance of PM in other settings, such as aviation and daily life (Dismukes, 2008; Marsh, R. L., Hicks, & Landau, 1998), the mechanisms responsible for PM impairment through sound, and distractions in general, are worthy of further exploration. It has to be acknowledged, though, that the highly specific setting in which both the observations in **Chapter 3** and the experiment in **Chapter 6** were executed, limits the generalizability.

The interdisciplinary nature of this project is another one of its strengths. By integrating methods and knowledge from nursing practice, psychology and the built environment, the main findings and implications contribute to these fields in a holistic manner. However, it also comes with the risk of missing vital knowledge in one of these fields regarding the methods employed or our interpretation of the findings. It was tried to reduce this risk by building on the experience and knowledge from different disciplines within the research team, and to include a nurse, fulfilling a master's degree in nursing science in the execution and analysis of the observations presented in **Chapter 3**. Close collaboration with the hospital in which the observations and experiments were conducted also helped to reduce this risk.

7.3.2 The approach

An aspect that can be regarded as both a strength and a limitation is the explorative nature of the approach. The data collection described in **Chapter 3**, combining several methods, as well as the experiment conducted in **Chapter 6** should be considered as pilot studies as their validation is limited. Furthermore, due to the confidential nature of the data collected in **Chapter 3**, the analyses presented in **Chapter 4** were conducted by the author only. This reduces both the generalizability of results and the direct use of the approach in other settings. Another factor related to the exploratory nature of the project are the small sample sizes that were used. Especially in **Chapter 6**, the small sample size of participants in the experiments limited the statistical power of the results. Despite these limitations, valuable insights were gained as a result of the approach.

This project started with a literature study with a narrow focus (**Chapter 2)**. Although the scope of the exploration that followed was a direct result of the insights that were gained in this chapter, in retrospect, this literature study does not fully capture the broad perspective on the role of sound at the workplace. Future studies on how people interact with the physical aspects of the built environment could benefit from a broader study of the literature addressing the interaction of people with their environment in general.

This also applies to addressing the three challenges presented in **Chapter 3.** They all relate to contextual factors that are hard to capture in a laboratory. Although in other design disciplines such as human computer interaction or industrial design these challenges are well recognized, and methods and approaches are adopted to face them, they are less familiar in studying the influence of the physical aspects of the built environment. Broader exploration of the available methods for context-of use analyses such as context-mapping (Visser, Stappers, Van der Lugt, & Sanders, 2005) could be beneficial in future studies.

The approach, that was adopted after the focused literature study presented in **Chapter 2** is schematized in Figure 7-1. It has led to valuable insights, which are described in section 7.2. However, the whole process is, due to its exploratory nature and due to the use of audio recordings, very time consuming. Given the narrow scope, in our case prospective memory in a nursing ward, and the consequential limited generalizability of findings, this can be considered a limitation. The approach can be considered most valuable in settings with very critical outcomes, in which the direct translation of results to the applied setting is required.

The repeatability of the open-minded observation of a workplace, which was the first step in our approach, is debatable. The prior knowledge and interests of the observers are expected to play a role. Furthermore, it can be questioned whether an observer can keep the same open-mindedness in a second observation. While a different researcher might focus on different parameters after the initial observation, we do not believe this makes the current results of lesser value.

The second step in our approach, a literature study based on the outcome of the initial observation, can strengthen the motivation to focus on a specific theme if confirming literature is found. However, it is also a danger that unexplored themes remain unexplored if a lack of supporting literature leads to ignoring a theme in the final data collection.

In the observation study presented in Chapters 3 to 5, the TA method, thinking aloud was a key element in the data collection. There are however some limitations that need to be acknowledged when using this method. As already stated in the discussion sections of both Chapter 4 and Chapter 5, using TA requires some practice for which there was no time during the observations. Differences in TA use could have led to both a dark number of distractions and formed intentions. Furthermore, it is questioned by some to what extent TA provides a complete mental image and influences thinking, see (Durning et al., 2013) for an elaboration.

To address these limitations arising from using TA, several other methods could be suitable for future explorations of distractions and PM at the workplace. Such methods include very objective methods such as analyzing gazing behavior using mobile eye-tracking or tracking mind wandering using video-based pupillometry to discover sources of distraction. Such methods however could be more obtrusive or impractical due to privacy issues. More qualitative methods, originating from design disciplines, are also available that potentially allow for a more in-depth analysis of how people deal with distractions in the context of their workplace, or how people form, encode and retrieve intentions. From Context-mapping, for example, which deals with studying people's interaction with products (Visser et al., 2005), a parallel could be drawn to studying peoples interaction with the environment. As a form of participatory design, context mapping requires the involvement of the user to create an understanding of the context in which a product is used. Co-design methods could be very useful in the design and evaluation of unobtrusive tools to prevent missed care, such as discussed in section 7.2.2.2.

Furthermore, it has to be noted that although our analyses of PM, distractions and interruptions in a nursing ward helped to model a more realistic experiment, it cannot be stated that the complexity of the nursing job was fully captured here. We argue that while it is necessary to focus on specific themes, and PM is a critical factor in the job performance of a nurse, there are other important themes and corresponding outcomes.

Finally, an important strength of the approach is the development of the ecologically valid experiment presented in **Chapter 6**. The knowledge and insights gained in analyzing the results of the observation study, presented in **Chapters 3, 4 and 5** were important contributors to both the sound conditions and the experimental task that was developed. However, further validation of the experimental task is a necessary next step in the future use of Virtual Shift.

7.4 **Future directions**

In **Chapter 2,** a conceptual model was suggested on the influence of the sound environment on task performance. This model guided the exploration presented in **Chapters 3 to 5** which has aided the development of the ecologically valid experimental design presented in **Chapter 6**. However, as in any project, our scope, resources and hours were not unlimited, and decisions were made that left topics or new insights regarding the factors included in our conceptual model unexplored. In this section we will provide our perspective on these topics which can be seen as suggestions for future research directions. The main factors from the conceptual model in Figure 2-3 are used to structure these suggestions.

7.4.1 **Factors influencing the sound environment**

As described in **Chapter 2,** the influence of room acoustic interventions is dependent on the size and shape of a room. In **Chapter 6**, the sound conditions were modelled based on an existing nurses' station. This was a small (20 m^2) room with a large glass surface. Nurses' stations take many shapes and sizes and the effect of replacing a ceiling will lead to a different effect on the sound environment in different rooms. To increase the generalizability of the findings, extending the scope to different room types would be a logical step. In doing so, special attention should be paid to the room size which can greatly influence the distance between sources (distracting conversations) and receiver (person who is performing a focal task) and therefore the influence of room acoustic parameters on the intelligibility of background speech. Other aspects to take into account in future studies are the number of people, more specifically, the number of simultaneous talkers in a room, and the role of other sound sources.

The observations described in **Chapter 3** have been performed in a recently built hospital with single-patient rooms only. In a recent review it was stated that the benefits of single-patient rooms outweigh the disadvantages (Taylor, Card, & Piatkowski, 2018). Furthermore, in both Canada and the United States, single-patient rooms are recommended for new hospitals (Facility Guidelines Institute, 2014). However, there are still many hospitals in which patient rooms are shared which has consequences for the sound environment in the ward. In further explorations of the sound environment in hospital wards, different ward types should be included and compared to each other.

7.4.2 **Task type**

The task that was explored in this thesis was the forming and retrieving of PM intentions. Forming and retrieving of PM intentions was logged in the observation study described in **Chapter 3**. These observations took place in two surgical wards of a recently built hospital with single-patient rooms. Due to the single rooms, when the nurses were with a patient, other patients could not add to the PM load by asking questions just by being visible for the nurse. For these same reasons, other patients could not serve as a reminder for to be retrieved intentions. Furthermore, the workflow of nurses can be very different in other ward types, non-surgical wards for example, or intensive care units. This is also likely to affect the forming and retrieving of PM intentions, as well as the possible consequences of PM failures. As the role of PM in the job of nurses is likely to be influenced by the type of ward and the way of working of a hospital, a logical next step would be to extend the scope to different wards and different hospitals.

The results in **Chapter 5** indicated that perceived task priority is a predictor of PM performance of nurses. This is in line with literature on the role of task importance in PM performance (Kliegel et al., 2004). However, in the experiment described in **Chapter 6,** perceived task priority, or task importance, was not measured for the PM tasks included in the experiment. The main reason not to include this factor was to not further increase the duration of the experimental procedure. In further development and validation of the experimental task, Virtual Shift, this aspect should be taken into account. In the current version, differences between the perceived priorities of the tasks in the three scenarios have possibly influenced the results. It was aimed to reduce this risk by counterbalancing the sound conditions and patient scenarios and by modeling the PM task as a random factor in the statistical analysis.

Another factor that is considered to moderate the effect of the sound environment, more specifically background speech on task performance is task difficulty (Sörqvist & Marsh, 2015). In the experiment described in **Chapter 6**, Virtual Shift, the difficulty of the task is related to many aspects. These are the number of PM tasks that have to be remembered, the content of what has to be membered, the complexity of the decisions participants are required to make when encountering an event and the number and ‘obviousness’ of cues that are embedded in the events. For direct translation of the results to applied settings, the difficulty of the experimental task should be comparable to practice. This aspect of the experimental task, Virtual Shift, needs further validation.

7.4.3 **Personal factors**

The target group addressed in this thesis are nurses. In the observations described in **Chapter 3**, and the experiment described in **Chapter 6**, participants were drawn from the actual target group. However, as discussed in **Chapter 2**, there are several other personal factors that are important aspects to consider when exploring the effects of sound on task performance. Examples are age (also affecting hearing ability), working memory capacity and noise sensitivity. These aspects were not addressed in the analysis presented in **Chapter 4** and the experiment described in **Chapter 6**. Collecting data on the personal characteristics known to moderate the effect of sound on performance is something that could be addressed in future studies.

7.4.4 **Other environmental factors**

The conceptual model presented in **Chapter 2** includes 'other environmental factors' as a factor influencing the effect of sound on task performance. Assessing the combined effects of different sensory modalities was outside the scope of our project. However, we consider a holistic evaluation of the environment an important aspect to address in future studies.

7.5 Concluding remarks

The aim of this thesis was to explore the influence of the sound environment on nurses' task performance in the context of a healing environment. Valuable insights regarding design decisions in the built environment, as well as the task performance of nurses were gained.

The sound environment at a workplace has the potential to affect the performance of professionals and needs to be addressed. In the design of the indoor sound environment, the interpretation of studies on the impact of sound on cognitive performance has to be done with caution. Translating findings to applied settings requires knowledge on how the workplace is used, which tasks are performed and which sound sources –including their behavior- can be expected. It is our aspiration that the work presented in this thesis inspires future studies on sound and task performance to carefully consider the type of task, the sound environment at a workplace and their interaction. Important questions to answer are which aspects of a job are critical to its overall performance, and how can the sound environment contribute to a good performance on these aspects.

7

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Appendix

Appendix A – Chapter 2: Inclusions after second review round

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Appendix B - Observation study

B1Recruitment Letter observation study

Meander Medisch Centrum Amersfoort

Geachte heer/mevrouw,

In februari en maart wordt er op de afdeling waarop u werkzaam bent een onderzoek uitgevoerd dat zich richt op de taken van verpleegkundigen. Middels deze brief willen we vragen of u interesse heeft om mee te werken aan dit onderzoek. Wat er bij deelname van u gevraagd wordt, is hieronder kort beschreven. Het onderzoek zal tijdens het volgende teamoverleg ook nog toegelicht worden, u kunt dan ook aangeven of u mee wil werken. U ontvangt daarop een informatiebrief met daarin een meer uitgebreide toelichting en een duidelijke instructie.

Onderzoeksmethode en procedure

Het onderzoek dat zal gaan plaatsvinden is een observatiestudie gecombineerd met een vragenlijst. Beiden worden hier afzonderlijk besproken.

Observatiestudie
Data rondom de taken van een verpleegkundige worden verzameld tijdens zogenaamd 'job-shadowing', dit houdt in dat er tijdens een deel van uw dienst twee onderzoekers met u meelopen. U wordt gevraagd om uw werk uit te voeren zoals u dat gewend bent en u niet door de aanwezigheid van de onderzoekers te laten beïnvloeden. Een bijkomend aspect is dat u gevraagd wordt uw gedachten te verbaliseren (hardop uitspreken) gedurende de observatieperiode. Bij deelname ontvangt u een duidelijke instructie over welke gedachten wel, en welke niet uitgesproken hoeven te worden. De onderzoekers lopen met u mee vanaf de start van de ochtenddienst, de observaties stoppen na 3 uur.

Vragenlijst
Tijdens uw lunchpauze komen de onderzoekers kort bij u terug om u een vragenlijst voor te leggen. Dit zal tussen de 20 en 25 minuten van uw tijd kosten.

Belangrijk om te vermelden is dat u pas na het afnemen van de vragenlijst toestemming geeft tot het gebruiken van de verzamelde data. De reden hiervoor is dat pas op dat moment duidelijkheid verschaft kan worden over de exacte vraagstelling achter het onderzoek, omdat dit mogelijk de resultaten kan beïnvloeden. Voorafgaand aan het onderzoek geeft u toestemming om de data te verzamelen, maar nog niet om deze te gebruiken.

<u>Overige belangrijke aspecten:</u>

- U kunt zich op elk gewenst moment terugtrekken uit het onderzoek, hier worden geen gevolgen aan verbonden.
- Wij verzamelen uw persoonlijke gegevens niet, wel zullen we vragen om enkele kenmerken zoals leeftijd, werkervaring en opleidingsniveau.
- Er worden geen patiëntgegevens verzameld.

Als dank voor uw tijd en moeite ontvangt u een kleine vergoeding bij deelname.

Tijdens de teamvergadering is er de gelegenheid om vragen te stellen. Als er daarna nog vragen zijn kunt u terecht bij Ellerieke Veenendaal, Manager Kliniek, die u indien nodig met ons in contact zal brengen.

Alvast bedankt en hartelijke groeten,

Het onderzoeksteam

B2 Information letter for participants

Meander Medisch Centrum Amersfoort

Geachte heer/mevrouw,

U heeft aangegeven interesse te hebben om mee te werken aan ons onderzoek naar de taken van een verpleegkundige, daar zijn we heel blij mee! De informatie in deze brief en in de bijlage zijn alles wat u nodig heeft om mee te kunnen doen. De procedure die nu volgt bestaat uit een 5-tal stappen:

1. U leest deze brief en de bijlagen goed door en neemt op basis hiervan opnieuw een besluit wat betreft deelname.
2. Indien u besluit deel te nemen kunt u het toestemmingsformulier in de bijlage ondertekenen. Let op: het gaat hier alleen om uw toestemming wat betreft de dataverzameling, u ontvangt bij de afronding van uw deelname nog een formulier dat u kunt ondertekenen om ons toestemming te geven de verzamelde data ook te gebruiken.
3. In februari en maart vind de dataverzameling plaats. In samenspraak met u en uw leidinggevende wordt een definitieve dag voor de observaties gekozen, dit zal op een dag vallen waarop u al ingeroosterd bent voor een dagdienst.
4. Voorafgaand aan de observatie nemen we telefonisch contact met u op om eventuele onduidelijkheden te verhelderen en de procedure nog eens door te nemen. Er wordt tijdig bij u aangegeven wanneer u ons telefoontje kunt verwachten.
5. Na afronding van de observatie en de vragenlijst wordt uw toestemming gevraagd om de verzamelde data te gebruiken. Daarnaast wordt u gevraagd niet over de inhoud van het onderzoek te spreken met collega's omdat dit de resultaten van eventuele observaties bij uw collega's kan beïnvloeden. U wordt gevraagd hiertoe een geheimhoudingsverklaring te tekenen.

In de bijlagen van deze brief vind u achtereenvolgens een beschrijving van de observatieprocedure en de vragenlijst, een instructie m.b.t. het verbaliseren van uw gedachten tijdens de observatie en een toestemmingsformulier m.b.t. het verzamelen van de data.

Bij vragen kunt u terecht bij mevrouw Ellerieke Veenendaal, die u indien nodig met ons in contact zal brengen.

Nogmaals vriendelijk bedankt en hartelijke groeten,

Het onderzoeksteam.

Bijlage 1: Procedure observatie en vragenlijst

In deze bijlage wordt precies beschreven wat deelname aan ons onderzoek inhoudt, en wat er van u als deelnemer verwacht wordt.

De data die voor dit onderzoek wordt in twee delen verzameld:

1. Observatie gedurende de eerste 3 uur van de dagdienst.
2. Het invullen van een vragenlijst tijdens uw lunchpauze.

<u>Observatie tijdens dienst, "job shadowing"</u>

Twee onderzoekers lopen gedurende de eerste 3 uur van uw dienst met u mee, er worden aantekeningen gemaakt. Het gaat om een niet-participerende observatie, dit betekent dat de onderzoekers geen interactie met u of uw collega's hebben. Iedereen op de afdeling, inclusief patiënten zal hiervan op de hoogte worden gesteld. Voor bezoek en collega's van andere afdelingen hangt er een brief bij de ingangen van de afdeling.

Het is voor het onderzoek van belang dat uw gedachtenproces in kaart wordt gebracht. Hiertoe wordt u gevraagd om hardop te denken. Dit wil zeggen dat u de dingen die u doet, ziet, hoort, beslist en plant hardop uit spreekt. Deze onderzoeksmethode heet de "think-aloud method" (TA). Om u goed voor te bereiden hierop vind u in de tweede bijlage een uitleg over hoe deze methode in zijn werk gaat. Wanneer u tijdens de observaties langer dan een minuut stil valt, zult u van de onderzoekers een reminder krijgen.

Een van de onderzoekers draagt tijdens de observatie een kleine audiorecorder. De opnames die gemaakt worden dienen ter controle van de data, ze worden beveiligd opgeslagen en zijn alleen toegankelijk voor de hoofdonderzoeker. Er worden transcripten gemaakt van de opnames die geen namen of andere gegevens die tot een persoon te herleiden zijn bevatten.

Buiten het feit dat u uw gedachten hardop uitspreekt, doet u uw werk net als anders. We vragen ook uw collega's om op de dag van de observatie zoals gebruikelijk met u te communiceren en samen te werken. Het is de bedoeling dat er een goed beeld verkregen wordt van de normale gang van zaken. De data is het meest betrouwbaar wanneer u de onderzoekers als 'niet aanwezig' beschouwt. Communiceer dus op de voor u gebruikelijke manier met patiënten, collega's en bezoekers.

De onderzoekers zullen ook met u meelopen wanneer u een patiëntenkamer binnenloopt. De patiënten die al op de afdeling liggen zijn al op de hoogte van het onderzoek, u kunt echter bij een eerste bezoek aan elke patiënt nog kort de volgende mededeling doen:

"Dit zijn twee onderzoekers die kijken naar de taken van verpleegkundigen. Ze lopen mee, maar zeggen niets, u kunt doen alsof ze er niet zijn. Ze verzamelen geen patiëntengegevens"

Wanneer patiënten aangeven dat ze bezwaar hebben tegen de opnames, kunt u bij deze patiënten de opname laten pauzeren, ook hiervan zijn de patiënten op de hoogte. De onderzoeker zal dan op uw verzoek de opname tijdelijk stopzetten.

De onderzoekers zullen aanwezig zijn vanaf de overdracht, en u daarna kort vragen de planning voor de ochtend te beschrijven. Daarna begint u uw dienst zoals gebruikelijk en zullen de onderzoekers u in stilte volgen. Ze zullen zich daarna terugtrekken waarna u uw dienst af kunt maken zoals u gewend bent. Tijdens uw lunchpauze komen de onderzoekers nog even bij u terug met een vragenlijst.

Vragenlijst tijdens lunchpauze

Bij aanvang van uw lunchpauze wordt u gevraagd om de onderzoekers op te zoeken in een daarvoor aangewezen ruimte. Op basis van de verzamelde data zullen u een aantal vragen voorgelegd worden, de inhoud van deze vragen kunnen we nu nog niet met u delen omdat dit de resultaten kan beïnvloeden. De betrouwbaarheid van uw antwoorden is het hoogst als u niet te lang nadenkt bij elke vraag. De vragenlijst bestaat uit twee delen, na het eerste deel wordt het doel van het onderzoek toegelicht, zodat u inzicht krijgt in de data die verzameld is. Op basis daarvan wordt u gevraagd om toestemming te geven deze data te gebruiken.

Belangrijk om te weten is dat het onderzoek geenszins een persoonlijke beoordeling of evaluatie van uw werk is.

We verwachten dat het invullen van de vragenlijst tussen de 20 en 25 minuten zal duren. U kunt er voor kiezen uw lunch te eten tijdens het invullen van de vragenlijst, maar dit hoef uiteraard niet. De onderzoekers zijn in de ruimte aanwezig om tijdens het invullen eventuele vragen te beantwoorden.

B3 Informed Consent forms and non-disclosure agreement observation study

TOESTEMMINGSFORMULIER

(Informed Consent)

behorende bij het onderzoek met TWO nummer 17-02

"De uitvoering van verpleegkundige taken volgens 'prospective memory' en de geluidsomgeving op een verpleegafdeling."

Door dit toestemmingsformulier te tekenen verklaar ik het volgende:

- Ik heb de informatiebrief voor de proefpersoon gelezen. Ik kon aanvullende vragen stellen. Mijn vragen zijn genoeg beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen helemaal vrijwillig is. Ik weet dat ik op ieder moment kan beslissen om toch niet mee te doen. Daarvoor hoef ik geen reden te geven.
- Ik weet dat sommige mensen mijn gegevens kunnen zien. Die mensen staan vermeld in de informatiebrief.
- Ik geef toestemming om mijn gegevens te gebruiken, voor de doelen die in de informatiebrief staan.
- Ik geef toestemming om mijn onderzoeksgegevens 5 jaar na afloop van dit onderzoek te bewaren.

Ik heb goed nota genomen van alle andere punten uit de informatiebrief voor proefpersonen.

Naam proefpersoon	handtekening	datum en plaats
…………………………………………	…………………	……………………

Als onderzoeker van dit onderzoek verklaar ik dat ik bovengenoemde deelnemer heb uitgelegd wat deelname inhoudt en dat ik borg sta voor de privacy van zijn / haar gegevens.

Naam onderzoeker	Handtekening	Datum en plaats
………………………	……………………………	………………………………

A

meander
MEDISCH CENTRUM

TOESTEMMINGSFORMULIER

(Informed Consent)

behorende bij het onderzoek met TWO nummer 17-02

Door dit toestemmingsformulier te tekenen verklaar ik het volgende:

- Ik heb de informatiebrief voor de proefpersoon gelezen. Ik kon aanvullende vragen stellen. Mijn vragen zijn genoeg beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen helemaal vrijwillig is. Ik weet dat ik op ieder moment kan beslissen om toch niet mee te doen. Daarvoor hoef ik geen reden te geven.
- Ik weet dat sommige mensen mijn gegevens kunnen zien. Die mensen staan vermeld in de informatiebrief.
- Ik geef toestemming om mijn gegevens te verzamelen, voor de doelen die in de informatiebrief staan.
- Ik weet dat ik nog geen toestemming geef om mijn gegevens te gebruiken en op te slaan. Ik kan na de dataverzameling nog aangeven dat mijn gegevens niet gebruikt mogen worden.
- Ik wil meedoen aan dit onderzoek.

Ik heb goed nota genomen van alle andere punten uit de informatiebrief voor proefpersonen.

Naam proefpersoon	handtekening	datum en plaats
…………………………………	………………	……………………

Als onderzoeker van dit onderzoek verklaar ik dat ik bovengenoemde deelnemer heb uitgelegd wat deelname inhoudt en dat ik borg sta voor de privacy van zijn / haar gegevens.

Naam onderzoeker	Handtekening	Datum en plaats
....	....	....

B4 Information letters for patients and visitors

Meander Medisch Centrum Amersfoort

Geachte heer/mevrouw,

Op de afdeling waar u verblijft wordt een onderzoek uitgevoerd naar het werk van verpleegkundigen. In het kader van dit onderzoek worden er observaties uitgevoerd door externe onderzoekers. Zij volgen gedurende de eerste drie uur van een dagdienst één verpleegkundige op de voet. Ze kijken, luisteren en maken aantekeningen maar nemen niet deel aan gesprekken en voeren geen zorgtaken uit.

Onderdeel van de observatiestudie is dat de betreffende verpleegkundige gevraagd is om hardop te denken, om het gedachtenproces van een verpleegkundige in kaart te brengen. Om deze gegevens op te slaan, draagt de verpleegkundige een draagbare audiorecorder met zich mee waarop alles wat hij of zij zegt opgenomen wordt. Ondanks dat het onderzoek niet gericht is op patiënten, kunnen deze opnames wel enkele patiëntgegevens bevatten. In het geval dat de betreffende verpleegkundige met u in gesprek is zal dat ook worden opgenomen. De onderzoekers hebben om de privacy van patiënten, bezoekers en medewerkers te waarborgen een contract getekend waarin de volgende afspraken gemaakt zijn:

- De audio opnames worden versleuteld opgeslagen in een beveiligde omgeving gedurende de loop van het onderzoek en tot 5 jaar na afronding van het onderzoek. Hierna worden de gegevens verwijderd.
- Alleen de hoofdonderzoeker, mevrouw J. Reinten heeft toegang tot deze data, in geval van nood kan toegang verschaft worden aan professor H.S.M. Kort.
- De audiodata wordt binnen twee weken getranscribeerd, hierbij worden geen gegevens die tot een persoon te herleiden zijn opgenomen. Alleen de transcripten van de gegevens worden gebruikt voor verdere analyse.

Indien u bezwaar heeft tegen het maken van de audio opnames in uw bijzijn kunt u dit bij de verpleegkundige aangeven. Hij of zij zal de opnames dan tijdelijk pauzeren.

De onderzoekers dragen alleen het jasje van een verpleegkundig tenue boven de normale kleding. We verzoeken u vriendelijk niet de interactie aan te gaan met de onderzoekers.

Indien u nog vragen heeft over het bovenstaande kunt u terecht bij mevrouw Ellerieke Veenendaal

Alvast vriendelijk bedankt voor uw medewerking,

Hartelijke groeten,

Jikke Reinten

Meander Medisch Centrum Amersfoort

MEDEDELING

Op de afdeling die u nu betreedt wordt een onderzoek uitgevoerd naar het werk van verpleegkundigen. In het kader van dit onderzoek worden er observaties uitgevoerd door externe onderzoekers. Zij volgen gedurende de eerste drie uur van een dagdienst één verpleegkundige op de voet. Ze kijken, luisteren en maken aantekeningen maar nemen niet deel aan gesprekken en voeren geen zorgtaken uit.

De onderzoekers dragen alleen het jasje van een verpleegkundig tenue boven de normale kleding. We verzoeken u vriendelijk niet de interactie aan te gaan met de onderzoekers.

Onderdeel van de observatiestudie is dat de betreffende verpleegkundige gevraagd is om hardop te denken, om het gedachtenproces van een verpleegkundige in kaart te brengen. Om deze gegevens op te slaan, draagt de verpleegkundige een draagbare audiorecorder met zich mee waarop alles wat hij of zij zegt opgenomen wordt. Ondanks dat het onderzoek niet gericht is op patiënten, kunnen deze opnames wel enkele patiëntgegevens bevatten. In het geval dat de betreffende verpleegkundige met u in gesprek is zal dat ook worden opgenomen. De onderzoekers hebben om de privacy van patiënten, bezoekers en medewerkers te waarborgen een contract getekend waarin de volgende afspraken gemaakt zijn:

- De audio opnames worden versleuteld opgeslagen in een beveiligde omgeving gedurende de loop van het onderzoek en tot 5 jaar na afronding van het onderzoek. Hierna worden de gegevens verwijderd.
- Alleen de hoofdonderzoeker, mevrouw J. Reinten heeft toegang tot deze data, in geval van nood kan toegang verschaft worden aan professor H.S.M. Kort.
- De audiodata wordt binnen twee weken getranscribeerd, hierbij worden geen gegevens die tot een persoon te herleiden zijn opgenomen. Alleen de transcripten van de gegevens worden gebruikt voor verdere analyse.

Indien u nog vragen heeft over het bovenstaande kunt u terecht bij mevrouw Ellerieke Veenendaal.

Alvast vriendelijk bedankt voor uw medewerking

B5 Example Questionnaire (empty form with example PM tasks)

Vragenlijst behorende bij observatiestudie

Toelichting:
U heeft deze ochtend deelgenomen aan een observatiestudie. Twee onderzoekers hebben gedurende de eerste drie uur van uw dienst met u meegelopen en aantekeningen gemaakt. De vragenlijst op de volgende pagina's is gebaseerd op deze aantekeningen. Lees deze instructie goed door voordat u de vragenlijst invult.

De vragenlijst bestaat uit twee delen. U kunt na het lezen van de instructie meteen beginnen met het invullen van deel 1. Wanneer u deel 1 ingevuld heeft kunt u de onderzoeker waarschuwen. Hierna volgt nog een extra toelichting op het onderzoek en ontvangt u deel 2 van de vragenlijst.
U wordt eerst gevraagd om een aantal algemene gegevens in te vullen, daarop volgt de vragenlijst.
In deze vragenlijst wordt gebruik gemaakt van een visuele analoge schaal, dit is een horizontale lijn van 10 cm met aan beide uiteinden twee tegenovergestelde begrippen. U kunt de vraag beantwoorden door een verticaal streepje te zetten op de plek die volgens u het meest overeenkomt met uw mening. De afstand tussen uw streepje en de eindpunten van de lijn wordt dan opgemeten.
Deze vragenlijst en de observaties zijn geenszins een beoordeling of evaluatie van u of de manier waarop u uw werk doet. De gegevens worden losgekoppeld van u als persoon.

Algemene gegevens

Code:
Datum:
Afdeling:

Leeftijd:
Geslacht:
Werkervaring totaal:
Werkervaring afdeling:
Opleiding:

Deel 1

Vraag 1.

Diensten variëren per dag in drukte. Hoe heeft u de werkdruk ervaren afgelopen dienst?

	Laag	Hoog
Geef op de balk aan hoe u gedurende *deze* ochtend de **werkdruk ervaren heeft**		

Toelichting:

Vraag 2.

Tijdens de afgelopen dienst zijn er een behoorlijk aantal verpleegkundige taken aan bod gekomen, hiervan is een lijst opgesteld. We vragen u om per verpleegkundige taak de prioriteit die u hieraan geeft te koppelen. Denk niet te lang na over uw antwoord ga in op uw eerste gedachte.

Geef achter elke taak op de balk aan welke **prioriteit** u deze taak gegeven heeft gedurende *deze* ochtend	**Laag**	**Hoog**
1. Rapportages lezen		
2. Pillen delen		
3. Controle Kamer xx		
4. Controle Kamer xx		
5. Controle Kamer xx		
6. Kamer xx wassen		
7. Kamer xx wassen		
8. Kamer xx wassen		
9. Monitoren: Kamer xx naar OK?		
10. Visite uroloog (8.00)		
11. Visite plastisch (bij komst)		
12. Geen bloedverdunners Kamer xx		
13. Ontslagmedicatie Kamer xx		
14. Kamer xx op toilet helpen		

Deel 2

In dit tweede deel van de vragenlijst komen de verpleegkundige taken uit deel een nog en keer aan bod. Deze taken zijn geformuleerd op basis van de door u uitgesproken gedachten tijdens de eerste drie uur van uw dienst.

Een deel van deze taken zijn Prospective memory taken (PM), dit betekent dat er tijd zit tussen het plannen en uitvoeren van de taak. Bij een PM taak is het van belang om op het juiste moment weer aan de taak te denken. Het doel van dit onderzoek was om inzicht te verkrijgen in het type en het aantal PM taken dat aan bod komt tijdens het werk als verpleegkundige. Daarnaast zoeken we naar factoren die van invloed kunnen zijn op PM taak uitvoering.

Graag horen we van u welke geplande taken u gedurende deze ochtend heeft uitgevoerd, en welke niet. Ook willen we weten of u de taak, naar uw mening, op tijd hebt uitgevoerd. Indien een taak is blijven liggen, of te laat is uitgevoerd vragen we u of dit bewust was (bijvoorbeeld omdat u op het moment dat u aan deze taak wilde beginnen de bewuste keuze maakte het uit te stellen) of onbewust (omdat u er niet meer op het juiste moment aan gedacht heeft).

We willen nogmaals benadrukken dat dit onderzoek geen beoordeling of evaluatie van u als persoon of uw werkzaamheden is. Ook kunnen de resultaten kunnen niet naar u als persoon herleidt worden. Voor een betrouwbaar resultaat vragen we u om de vragen op de volgende bladzijden geheel eerlijk in te vullen.

Nu het onderzoeksdoel bekend is vragen we u ook om bijgevoegd toestemmingsformulier te ondertekenen. Hiermee geeft u ons toestemming de verzamelde data ook te gebruiken.

Toelichting:

	Ja, op tijd	Ja, te laat		Nee	
		Bewust	***Onbewust***	***Bewust***	***Onbewust***
13. Ontslagmedicatie Kamer xx	o	o	o	o	o
Toelichting:					
14. Kamer xx op toilet helpen	o	o	o	o	o
Toelichting:					

Hartelijk dank voor uw medewerking! U kunt bij de onderzoeker aangeven dat u de vragenlijst heeft afgerond. Laat het ons vooral weten als er nog vragen of onduidelijkheden zijn.

Appendix C - Laboratory experiment

C1 Recruitment letter

HOGESCHOOL UTRECHT

Virtual Shift – Cognitief experiment met verpleegkundigen

Beste verpleegkundige,

Vanaf eind september wordt er een onderzoek uitgevoerd dat zich richt op de taken van verpleegkundigen. Het doel van het onderzoek is om inzicht te krijgen in het lezen van het EPD in verschillende werkomstandigheden. Middels deze brief willen we vragen of je interesse hebt om mee te werken aan dit onderzoek. Wat er bij deelname van je gevraagd wordt staat hieronder beschreven.

<u>Onderzoeksmethode en procedure</u>

Het onderzoek bestaat uit een experimentele studie met proefpersonen. De doelgroep voor deze studie zijn verpleegkundigen die werkzaam zijn in het Meander Medisch Centrum.

Een proefpersoon wordt gevraagd om 3 keer een virtuele dienst te doorlopen onder verschillende omstandigheden. Deze virtuele dienst bestaat uit het bestuderen van fictieve patientendossiers (EPD) gevolgd door het doorlopen van een dagdienst in de vorm van een bordspel. Tijdens het bestuderen van het EPD wordt de proefpersoon gevraagd om hardop te denken om inzicht te krijgen in de keuzes die gemaakt worden, hiervan wordt een audio opname gemaakt.

Het experiment duurt 2,5 uur inclusief pauzes en zal plaatsvinden in een kantoorruimte in het Meander Medisch Centrum. Bij inschrijving krijg je de precieze locatie te horen.

Als dank voor je tijd en moeite ontvang je een vergoeding van 25,- euro in de vorm van een Bol.com cadeaubon.

Voorafgaand aan het experiment worden duidelijke instructies gegeven, voorbereiding is niet nodig.

<u>Overige belangrijke aspecten:</u>

- Wij verzamelen uw persoonlijke gegevens niet, wel zullen we vragen om enkele kenmerken zoals leeftijd, werkervaring en opleidingsniveau.
- Elke proefpersoon krijgt een IDnummer. De lijst waarop de namen van proefpersonen gekoppeld zijn aan IDnummers wordt apart van de onderzoeksdata bewaard en is alleen toegangelijk voor het onderzoeksteam.
- Er worden geen patiëntgegevens verzameld.
- Deelname aan het onderzoek is geheel vrijwillig en de deelnemer kan zich zonder enige gevolgen op ieder moment terug trekken uit het onderzoek.
- Voorafgaand aan het onderzoek geeft een proef toestemming om de data te verzamelen en te gebruiken middels een informed consent formulier.

Wanneer kun je meedoen:

- Je bent als verpleegkundige werkzaam in het Meander Medisch Centrum.
- Je bent bekend met het programma Easycare.
- Je beheerst de Nederlandse taal goed.

Wanneer ben je uitgesloten voor deelname:

- Je hebt Dyslexie
- Je hebt een gehooraandoening
-

Inschrijven en data:

Het onderzoek start op 25 september en loopt tot medio november.

Je kunt je via onderstaande link inschrijven voor een datum en een tijdstip. Er is ruimte voor twee deelnemers per dag, één voorafgaand aan de avonddienst (12.30 – 15.00) en één na afloop van de dagdienst (16:00 – 18:30).

https://doodle.com/poll/gx2brziypehiveuh

LET OP: vul in plaats van je naam, je email adres in. Nadat je een tijdstip gekozen hebt kun je niet meer terugzien wel tijdstip je gereserveerd hebt. Je ontvangt van de onderzoeker een mail met een bevestiging en de informatie over waar je moet zijn.

Mocht je graag mee willen doen op een ander tijdstip, mail dan gerust met de onderzoeker om een aparte afspraak te maken. Ook voor overige vragen kun je contact opnemen met de onderzoeker. De contactgegevens staan onderaan deze brief.

Alvast bedankt en hartelijke groeten,

Jikke Reinten

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C2 Informed consent form and non-disclosure agreement

TOESTEMMINGSFORMULIER

(Informed Consent)

behorende bij het onderzoek: *"Virtual Shift."*

Door dit toestemmingsformulier te tekenen verklaar ik het volgende:

- Ik heb de informatiebrief voor de proefpersoon gelezen. Ik kon aanvullende vragen stellen. Mijn vragen zijn genoeg beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen helemaal vrijwillig is. Ik weet dat ik op ieder moment kan beslissen om toch niet mee te doen. Daarvoor hoef ik geen reden te geven.
- Ik weet dat sommige mensen mijn gegevens kunnen zien. Die mensen staan vermeld in de informatiebrief.
- Ik geef toestemming om mijn gegevens te gebruiken, voor de doelen die in de informatiebrief staan.
- Ik geef toestemming om mijn onderzoeksgegevens 5 jaar na afloop van dit onderzoek te bewaren.

Ik heb goed nota genomen van alle andere punten uit de informatiebrief voor proefpersonen.

Naam proefpersoon	handtekening	datum en plaats
………………………………	………………	………………

Als onderzoeker van dit onderzoek verklaar ik dat ik bovengenoemde deelnemer heb uitgelegd wat deelname inhoudt en dat ik borg sta voor de privacy van zijn / haar gegevens.

Naam onderzoeker	Handtekening	Datum en plaats
………………………	………………………………	………………………………

HOGESCHOOL UTRECHT

Geheimhoudingsverklaring

behorende bij het onderzoek: *"Virtual Shift."*

Ondergetekende,

Naam proefpersoon:

- Verklaart hierbij dat hij/zij de informatie omtrent het doel van dit onderzoek die hem/haar door de onderzoekers zijn mede gedeeld, alsmede de inhoud en opzet van het experiment als strikt vertrouwelijk zal behandelen.

Handtekening: Datum : __ / __ / __

Curriculum Vitae

Curriculum Vitae

Jikke Reinten was born on July 6th 1985 in Venlo, the Netherlands. She finished her pre-university education at College Den Hulster in Venlo in 2003. As part of this education, she obtained the English A2 Language and Literature Certificate from the International Baccalaureate (IB). Immediately thereafter, she started the bachelor program Architecture, Urbanism and Building Sciences at Eindhoven University of Technology. After completing the bachelor program, she proceeded with the master program Physics of the Built Environment, also at Eindhoven University of Technology. In 2011 she received her master's degree and started as a building physics advisor for Royal HaskoningDHV. In this role, she performed measurements and simulations regarding building acoustics, lighting, thermal aspects, sustainability and fire safety for various building projects. In 2013, driven by a strong interest in the effects of sound on people, she started a new position as a Concept Developer in the healthcare segment at Saint-Gobain Ecophon. Here, she was responsible for the dissemination of knowledge on acoustics in healthcare amongst architects, advisors, and healthcare decision makers.

Since 2015 Jikke has been working as a PhD student at University of applied sciences and joined the research group Technology for Healthcare Innovations. During the course of her research she also worked as a lecturer for the Institute of the Built Environment, where she was involved in several building physics related courses. At the Eindhoven University of Technology she was part of the Building Acoustics research group. Whilst conducting her doctoral research, she has presented her work at national and international conferences. Since 2014 Jikke is a member of the editorial committee of the Dutch Flemish Building Physics Association.

After finishing the research presented in this thesis, Jikke joined TNO to continue studying the effects of external factors on human performance.

List of publications

List of publications

Journal publications (first author)

Reinten, J., Braat - Eggen, P. E., Hornikx, M. C. J., Kort, H. S. M., & Kohlrausch, A. G. (2017). The indoor sound environment and human task performance: A literature review on the role of room . *Building and Environment*, *123*, 315-332. https://doi.org/10.1016/j.buildenv.2017.07.005

Conference publications (first author)

Reinten, J., Kort, H. S. M., Hornikx, M. C. J., & Kohlrausch, A. G. (2019). Experimental design to measure the effect of room acoustics on prospective memory of hospital nurses. *In 23rd International Congress on Acoustics, 9-13 September, Aachen, Germany*.

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Journal publications (co-author)

Braat-Eggen, E., Reinten, J., Hornikx, M., & Kohlrausch, A. (2020). The influence of background speech on a writing task in an open-plan study environment. *Building and Environment*, *169*, [106586]. https://doi.org/10.1016/j.buildenv.2019.106586

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Conference publications (co-author)

Braat-Eggen, E., Reinten, J., Hornikx, M., & Kohlrausch, A. (2020). Studying for an exam in an open-plan study environment: Does background noise impair performance? Experimental design to measure the effect of room acoustics on prospective memory of hospital nurses. *In 23rd International Congress on Acoustics, 9-13 September, Aachen, Germany*.

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Acknowledgements

The idea of pursuing a doctorate started to evolve early 2014. Working in the field of healthcare acoustics at Saint-Gobain Ecophon, I more and more realized there was much to be explored regarding the effect of sound on people. More importantly, I wanted to actively take part in this exploration. This realization started with an internal conversation, but gradually I started to speak out my intention to family, friends and colleagues. As with many things in life you want to achieve, sharing it with the people around you, may indirectly or directly get you the help you need. So, now that the bulk of the work is behind me, it is time to express my gratitude to those without whom I could not have gotten this far.

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The impact of the indoor sound environment on building occupants has received an increasing amount of attention over the past years. It is well recognized that the sound environment can cause stress, disturbance, and affects cognitive task performance. The focus of this thesis is the sound environment in hospitals and its effect on nurses' task performance, which plays an important role in patient outcomes and patient satisfaction.

Adequate translation of the cognitive effects of sound to applied settings such as hospitals is challenging. The work presented in this thesis adresses this challenge through an in-situ observational study, followed up by a dedicated laboratory experiment. The observational study simultaneously focused on distractions by sound and a specific aspect of a nurse's work, which is to carry out intended activities at the right moment or time. This requires prospective memory (PM), a topic relatively unexplored in the context of nursing.

Based on the findings of the observational study, an experimental study was conducted, for which an experimental task in the form of a board game was designed to measure nurses' PM performance in different (realistic) sound conditions. The results indicate that background speech with a high intelligibility during the forming of intentions for tasks impairs the timely execution of these tasks. The thesis concludes with practical insights that can be used to improve the working conditions of nurses.

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