The effects of negative knowledge video training on medical students' non-technical skills in cardiopulmonary resuscitation

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Cardiopulmonary resuscitation (CPR) is a complex medical task that requires technical skills (TS) as well as non-technical skills (NTS). In medical education, CPR training focuses on teaching TS, although research has indicated that poor NTS are often the reason for medical errors. The aim of the present study was thus to investigate the effects of training on medical students' NTS performance. 80 medical students participated in an experimental design. The control group took part in traditional CPR training that focuses on TS. The experimental group participated in CPR training that addressed NTS and emphasised learning from errors. The results revealed significantly higher ratings in all NTS for the experimental group, indicating that NTS can be trained effectively. Using videos as instructional means to pinpoint errors in NTS increases students' CPR performance and they appear to learn from errors. A time-efficient intervention in medical education is enough to make a difference.

1 Introduction

Medical educators face the challenge of preparing their students for a complex clinical work environment in which they are able to deliver high-quality patient care. A study programme that primarily aims at the pure transfer of knowledge falls short of this mark, though. To keep up with dynamic changes in the field, ongoing political reforms aim to further develop and restructure medical education (Wissenschaftsrat, 2018). The Master Plan for Medical Studies 2020 (*Masterplan Medizinstudium 2020*) formulates strategic goals for improving medical education on a national level in Germany. According to this agenda, one key goal is to design more competence-based training to support the development of knowledge, skills and attitudes. Subsequently, greater emphasis is also placed on the non-technical skills (NTS; e.g. communicative and managerial skills) of future physicians, who often work in multidisciplinary and interprofessional teams. The German Association for Medical Education has also expressed the need for NTS in undergraduate education. Accordingly, a "learning objective catalogue for patient safety in undergraduate medical education" was published with the aim to unify curricular targets (Kiesewetter et al., 2016). Still, what should be taught in medical education and how to implement new instructional designs remain hotly debated topics (Wu & Busch, 2019).

Designing learning environments that improve medical students’ competencies efficiently seems to be an important goal for curriculum development. However, only a few studies have investigated the effect of teaching NTS in undergraduate medical education (Moll-Khosrawi et al., 2019). As it is difficult to implement radical changes in medical curricula (Choi-Lundberg et al., 2020), an alternative approach was chosen in the present study. The basic idea was to take an existing course and add competence-oriented elements. We were interested in whether we can see improvements in NTS after only slightly adjusting a traditional training format.

CPR is a medical action everyone – from medical professionals to laypersons – should be able to perform. CPR is defined by guidelines – for example, those of the European Resuscitation Council (ERC; Perkins et al., 2018) – which show that CPR is a complex task comprising both technical skills (TS) and NTS. TS involve skills such as chest compressions, ventilation and the use of an automated external defibrillator (AED). NTS refer to human factors containing cognitive and mental processes, such as task management or situational awareness, as well as social and interpersonal skills like teamwork and communication within CPR to apply the correct treatment (Flin & Maran, 2015). The ERC emphasises that both TS and NTS are required for effective CPR. NTS complement and enhance TS. Research has also found positive correlations between the two skill types (Flin & Maran, 2016; von Wyl et al., 2009). Moreover, enhancing particular NTS can be beneficial to professionals’ technical performance in a wide variety of medical domains (Hull et al., 2012).

1.1 Non-technical skills in cardiopulmonary resuscitation

Despite the importance of NTS, CPR training still mainly focuses on teaching technical performance without explicitly addressing NTS. Recent research shows that poor NTS are a significant cause of medical errors, and that insufficient NTS can lead to fatal medical accidents that harm patient safety and even cause patient death (Hinshaw, 2016; Monks & Maclennan, 2016; Odell, 2011; Truta et al., 2018). Improving these skills should reduce accidents (Uramatsu et al., 2017). Errors can happen from deficiencies in both TS (e.g. wrong drug administration) and NTS (e.g. bad communication), though. However, research shows that if errors occur in medical domains, they are more likely to happen due to insufficient non-technical performance. Most errors occur due to a lack of communication (Rovamo et al., 2015), wrong decision-making or a lack of situational awareness (Moorthy et al., 2005).

To investigate CPR performance, a reliable method that assesses both TS and NTS is required. While training dummies can be used to assess technical performance, assessing NTS is more challenging. NTS are usually latent skills and, depending on the respective medical domain, the skills physicians require can differ. For instance, surgeons need different NTS (e.g. explicit task management and communication during surgery) than radiologists (e.g. situational awareness when looking at X-rays). In the last decade, instruments have been developed to assess physicians' NTS in different medical disciplines: for instance, NOTSS (to assess surgeons' NTS) and ANTS (to assess anaesthetists' NTS; Flin et al., 2010; Yule et al., 2006). In the case of CPR, skills like task management, teamwork and situational awareness are important for good CPR performance (Porter et al., 2018; Wieck et al., 2018).

Simulated scenarios are typically used as instructional means to train CPR. Simulations are common learning environments in medical education (Flentje et al., 2018; Kern et al., 2011; Langdorf et al., 2014). The unique characteristic of simulations in medical education is that the complexity of a task can be imitated so that it feels authentic (Burke et al., 2017; Flentje et al., 2018; McRae et al., 2017; Sadideen et al., 2017). With the help of a training dummy, students learn to apply their newly gained skills and can delve into the situation, thus enriching their understanding. The advantage of a simulation is that medical students can practise complex tasks without having to fear serious consequences for the patient. Errors happen, of course, but they can be used for training purposes when students learn to manage them.

One major challenge in medical education is the limitation of time for curriculum topics. Although Choi-Lundberg et al. (2020) show that it is possible to reduce teaching hours without much impact on student learning outcomes, it remains difficult to adjust curricula themselves. Due to time restrictions, the focus of CPR training lies on imparting relevant technical components, while intensive NTS training currently seems infeasible. Without training NTS explicitly, however, it is questionable whether students can appropriately master these skills later. Prior research especially notes poor NTS performance in the surgery and anaesthesia domains (Flin et al., 2010; Yule et al., 2006). To equip medical students with the relevant skills for their future professions, it is important to examine instructional means and their effects.

1.2 Negative knowledge: A favourable occasion to learn from errors in medical education CPR training

At the medical workplace, errors can have detrimental consequences for patient safety and should therefore be prevented. Avoiding errors in professional practice seems most evident, but designing instructional means that foster correct behaviour is less straightforward. Scholars have taken different approaches to learning and training. Bandura (1986) regards errors as obstacles to learning, which unnecessarily slow the learning process. In his social-cognitive theory, Bandura stresses that learners can reproduce an observed behaviour. Instead of costly and painful faulty efforts, he proposes direct informative guidance that focuses on the correct behaviour with the help of a model. He also tells that reproduction is influenced by the learner's belief in his or her abilities to correctly execute that observed behaviour (Bandura, 2001).

However, as work activities are complex, there is a constant risk of something going wrong. Complex tasks are prone to errors, so it is common sense that errors cannot be completely avoided. Although errors endanger the attainment of desired goals, they are also a form of negative feedback, as they can indicate aspects that need further correction or refinement (Frese & Zapf, 1994; Gartmeier et al., 2008). When viewing errors as a form of feedback, this informative aspect can be used in learning. Gartmeier et al. (2008) describe learning from errors as a special form of experiential learning that plays a crucial role in professional development. Keith and Frese (2008) also take an explicitly positive view of errors for learning; in a meta-analysis, they investigate the effectiveness of a training method called error management training, in which errors are seen as a "*natural by-product of active learning*" (p. 59). Error management training is characterised by minimal guidance, active exploration and the explicit encouragement of making errors. Keith and Frese (2008) conclude that error management training is particularly effective for adaptive transfer tasks. Moreover, their meta-analysis revealed the positive effect of error management training, indicating that incorporating errors into training can be a more effective means of learning compared to training methods that focus on correct behaviours alone. Parviainen and Eriksson (2006) also recommend recognising the value of errors and failures as opportunities to learn. Similarly, Dyre et al. (2016) suggest exploring errors as learning in medical education rather than teaching error avoidance.

However, learning from errors is only possible if medical students are aware of errors and how to process them. They need to reflect on the causes and the effects, and understand how an error might be prevented next time. Thus, if students perceive an error as a critical event and consequently enrich and modify their knowledge base, they have learned. Trying to understand why errors occur and how best to prevent their repetition, Gartmeier et al. (2008) formulated the theory of negative knowledge. Negative knowledge is experiential knowledge about "*knowing what not to do*" (procedural aspect) and "*knowing what not to know*" (declarative aspect; Gartmeier et al., 2008). More precisely, negative knowledge means having awareness of one's competences and knowledge as well as acknowledging what one does not know. This includes knowing what not to do and acquiring skills to "unlearn" or "bracket" certain skills or knowledge that did not work in certain situations. Thus, practical experience within a specific (work) context can lead to obtaining negative knowledge. Errors provoke reflection and demand explanations, which results in interpreting situations differently (Gartmeier et al., 2015). Oser and Spychiger (2005) describe negative knowledge as a form of meta-knowledge, revealing a regulative impact on positive knowledge. In fact, negative knowledge is the outcome of learning from errors. It is beneficial, as it provides certainty, improves efficiency and enhances the quality and depth of reflection. Knowing what is wrong in combination with the awareness of what can potentially go wrong is a heuristic advantage (Gartmeier et al., 2008).

Medical students do not necessarily need to make errors themselves to learn from them. It is also possible to demonstrate authentic case examples with virtual patients in which errors occur in real-life scenarios. Urresti-Gundlach et al. (2017) point out that virtual patients need to present a realistic image of the real world to ensure authenticity without overwhelming learners. Confronting medical students with a CPR performance that went wrong due to insufficient NTS might be an effective training method to increase awareness and improve their NTS, as long as they analyse the error's causes, develop more appropriate strategies and implement these new strategies accordingly. Positive and negative models can support the generalisation of the targeted behaviours (Baldwin, 1992) and enhance learning, as well as transfer of knowledge (Taylor et al., 2005). Negative knowledge offers the potential to understand how to better avoid errors, and should thus be developed more purposefully at the individual level (Gartmeier et al., 2010).

The aim of the present empirical study was to train medical students in cardiopulmonary resuscitation (CPR) and examine the influence of newly incorporated videos on their NTS. For that purpose, we compared two different training methods and their effects on medical students' NTS performance. An emphasis was put on addressing NTS by learning from errors. We therefore addressed the following research question: How do short "negative knowledge-based video lessons" incorporated in traditional CPR training affect medical students' NTS? Our hypothesis was that medical students show poorer NTS after traditional CPR training that focuses on TS, as compared to medical students who participate in slightly adjusted CPR training that also addresses NTS and encourages learning from errors.

2 Method

2.1 Design

We chose an experimental design with factor training (A versus B) and the dependent variables task management, teamwork and situational awareness. The sample was split into an experimental and a control group. The control group received traditional CPR training (training A). The experimental group received slightly adjusted CPR training with a focus on NTS (training B). To ensure that time-on-task was equal, in-depth TS lessons were added to training A. Age, gender and resuscitation knowledge were considered control variables to ensure that possible effects were attributable to the training.

2.2 Training

Training A was a traditional 2-week (4 hours per day) CPR training with a focus on TS that was standardised within the respective clinical hospital in Germany. It consisted of theoretical lessons about resuscitation according to ERC guidelines. In addition, the training contained practical lessons: for example, how to perform chest compression or intubation. The participants performed simulated CPR using dummies. After their within-training performance, the students discussed their task execution together with the teacher. During the debriefing, the teacher triggered reflection, pointed out mistakes and provided feedback. Overall, the training mostly addressed TS such as drug delivery, intubation, chest compression and defibrillation. On two days of the 2-week course (Wednesday of the first week and Thursday of the second week), additional TS training was provided in the form of theoretical input. The duration of these extra input sessions took 30 minutes each, and repeated the most important TS in the CPR course: chest compression, intubation and ventilation, as well as medication. Approximately one third of the total course time was spent on theoretical input, while two thirds was used for practical exercises and debriefing. NTS were not explicitly addressed in this training.

Training B was similar to training A in that it was a 2-week CPR course with a focus on TS, with theoretical and practical training parts. However, instead of additional TS training, the participants received additional NTS lessons. On Wednesday of the first week of the course, the NTS lesson was a 30-minute presentation about NTS and their impact on medical performance. On Thursday of the second week of the course, the NTS lesson was a 30-minute video-based NTS training that demonstrated errors that can happen during CPR due to insufficient NTS.

The video was created based on the theory of negative knowledge and according to recommendations by Guo et al. (2014). The video showed three people performing simulated CPR using a training dummy on the floor of a common hospital staffroom. This informal setting creates a personal feeling on the learners' sides, and is more engaging than a high-fidelity studio recording. The video lasted 10 minutes, as short videos were found to be more engaging than longer ones (Guo et al., 2014). The demonstrated scenario in the video was divided into three sequences that included nine different medical errors. These errors addressed task management, teamwork and situational awareness (three errors per skill). The following examples illustrate errors that occurred in the video: a) error in task management: the emergency doctor did not clearly distribute particular tasks (chest compression and preparing an AED) between his team members, which led to confusion and time loss; b) error in teamwork: important information like cardiac rhythm was not communicated, and ambiguous communication led to administering the wrong medication; and c) error in situational awareness: the emergency doctor did not recognise that one of his crew members had physical contact with the patient just before the AED was used.

The full video was presented once, then discussed by the participants among themselves and with their teacher. The discussion lasted 20 minutes. If necessary, sequences of the video were played again, and the teacher emphasised the role of NTS in the respective situations. The aim was to show the participants what they did not know themselves, as well as to enlighten them to what not to do in certain situations during CPR. At the end of this part of the training, the participants received take-home messages that summed up the most important facts about NTS performance during CPR.

2.3 Participants

The sample consisted of 80 medical students (39 females, 41 males), all enrolled in their third clinical semester of medicine. Participants were randomly assigned to one of two groups. 40 (20 females, 20 males) participants were assigned to training A, 40 participants (19 females, 21 males) were assigned to training B. Before entering their clinical semester, all medical students had attended a first aid course that included short CPR lessons. None of the participants had had any other prior resuscitation experience in their medical study programme.

2.4 Instruments

To assess NTS as well as demographic data and control variables, we developed a questionnaire and observation form.

Questionnaire: A demographic questionnaire gathered age, gender and knowledge concerning resuscitation. This data was collected to ensure that the participants did not differ regarding these variables.

Observation: We followed an open and non-participant observation procedure to measure the extent of NTS mastered during CPR training. The skills task management, teamwork and situational awareness were observed. Task management describes the emergency doctors' ability to radiate sovereignty and to ensure the best possible CPR procedure through clear instructions and by guiding their assistants if necessary. The student who had the role of the emergency doctor had to choose the method of treatment and arrange duties (e.g. "Gives instructions to arrange drug administration or defibrillation"). Teamwork describes the way the emergency doctor interacts with the assistants and manages the workload within the team (e.g. "Does not overtax the assistants"). Situational awareness describes the emergency doctor's awareness of the current situation and available resources, as well as the extent of re-evaluating the situation during the CPR process (e.g. "Gathers information about patient status").

We then developed an observation form that consisted of 28 items. A factor analysis including all items revealed three sets of items. These three sets corresponded to the NTS categories reported in the literature: task management, teamwork and situational awareness. Internal consistency (Cronbach's α) showed the following values: task management (11 items) α = .92, teamwork (10 items) α = .87 and situational awareness (7 items) α = .72. The different items corresponded to the ANTS behavioural marker system (Flin et al., 2010). The rating was also adopted from the ANTS system. The items were scored on a 4-point Likert scale (1 = *poor*, 2 = *marginal*, 3 = *acceptable*, 4 = *good*). According to the ANTS system, participants should at least score acceptable (3) in all items; otherwise, their NTS performance is considered weak. To ensure the quality of the rating process, the observers were trained to develop a shared understanding of the observation form. Then, four observers watched the videotapes separately and rated each student's behaviour independently, not knowing whether the participants had taken part in training A or training B. Cohen's kappa assessed the inter-rater reliability with a satisfying score of κ = .81.

2.5 Procedure

Data were collected during eight standardised 2-week CPR training courses at a university hospital. At the start of the course, the participants filled in the demographic questionnaire. They were randomly assigned to either the control (training A) or the experimental (training B) group. At the end of the training, all participants performed simulated CPR in teams of three. The participant who had the role of the emergency doctor was videotaped. This resulted in 80 different videos (40 for each training). These videos were analysed. Each video was approximately 15 minutes long, so that the total recording time was about 20 hours.

To minimise non-systematic influences, both trainers were actively involved in designing the training courses and planned the additional TS and NTS lessons carefully. The trainers used identical course materials and examples and were encouraged to synchronise their instruction.

2.6 Analysis

We used a statistics programme to analyse the data (SPSS 24, IBM, Armonk, USA). Descriptive analyses were performed for the dependent variables task management, teamwork and situational awareness. MANOVA was calculated to compare the two training groups regarding the dependent variables. The control variables were used to ensure that possible effects were attributable to the respective training.

3 Results

None of the control measures (age, gender, resuscitation knowledge) was significantly related to any of the NTS measures.

For participants who received training A, the descriptive statistics revealed the following mean scores: task management at $M = 2.99$, $SD = .45$; teamwork at $M = 2.49$, $SD = .47$; and situational awareness at $M = 2.31$, $SD = .47$.

For participants who took part in training B, the NTS scores were higher: task management was at $M = 3.50$, $SD = .37$; teamwork at $M = 3.21$, $SD = .27$; and situational awareness at $M = 2.82$, $SD = .42$. MANOVA showed that these differences were statistically significant ($F(3,76) = 24.73$, $p < .001$; *Wilk's* $\Lambda = .51$, partial $\eta^2 = .49$). After the negative knowledge lessons, NTS performance was significantly better in task management ($F(1,78) = 29.55$; $p < .001$; partial $\eta^2 = .28$), teamwork ($F(1,78) = 70.99$; $p < .001$; partial $\eta^2 = .48$) and situational awareness ($F(1,78) = 26.53$; $p < .001$; partial $\eta^2 = .25$).

4 Discussion and conclusion

In the present study, we compared traditional CPR training to an adjusted one, and investigated their effects on medical students' NTS performance. NTS lessons were integrated into an existing training programme by means of a time-efficient video-based intervention. Based on the theory of negative knowledge, we assumed that confronting medical students with errors due to NTS in CPR would raise their awareness that a lack of NTS can have severe consequences for patient safety. To date, only a few studies have investigated the effect of teaching NTS in undergraduate medical education (Moll-Khosrawi et al., 2019), and experimental designs in NTS training research are often missing (Hagemann et al., 2017). Ongoing political reforms stress the importance of implementing learning environments in medical education that foster the acquisition of knowledge, skills and attitudes (Wissenschaftsrat, 2018). The ERC emphasises the significant role of NTS in resuscitation in particular. Therefore, intervention studies that examine the effects of NTS training are relevant and help enhance the understanding of what instructional means can work under certain conditions.

We hypothesised that medical students show poorer NTS after traditional CPR training that focuses on TS, as compared to medical students who participate in CPR training featuring negative knowledge-based video lessons addressing NTS. Our study results confirmed our hypothesis. Medical students in the experimental group showed significantly higher NTS than students in the control group. All examined NTS – task management, teamwork and situational awareness – improved. Based on Cohen (1988) and Chen et al. (2010), the effect size for the CPR training with the negative knowledge-based video lessons was large. A large effect size underlines the practical relevance of the found effects.

Accordingly, our study indicates that NTS can be trained effectively. As we were confronted with time restrictions, the training had to be kept to a minimum. The implementation of only a 30-minute theoretical input lesson, together with one short video and subsequent discussion, into CPR training already made a difference. Thus, 60 minutes, which we consider a feasible timeframe in medical education, led to changes in performance. It is important to note that this short period which had substantial effect, is part of a longer course and is not intended to replace the remaining course parts. The negative knowledge intervention may and should have effected other parts of the training and further practical work as well. It is beyond this study's scope to examine such effects. The finding is important for medical education, as the intervention can easily be added to existing courses and lead to better NTS performance. Hill et al. (2008) suggest comparing effect sizes with similar studies in the field. Accordingly, our results are in line with prior research. Hagemann et al. (2017) found in their experimental study that one brief seminar had positive effects on undergraduates' NTS. The intervention was a demonstration-based learning approach and lasted 90 minutes. Situational awareness, teamwork and decision-making improved significantly with effect sizes of $r = .50$, $r = .45$ and $r = .39$, respectively. Task management did not improve significantly.

Even if the results of our study are promising, some cautionary remarks should be considered. Although post hoc power analysis showed that our study had a power above .80, the effect sizes should be interpreted critically. We tried to standardise the setting as much as possible, but unsystematic influences caused by the teachers, students and group compositions cannot be ruled out completely. According to Ioannidis (2005) and Button et al. (2013), research findings are less likely to be true in the case of smaller sample sizes. Although our results were significant and revealed large effect sizes, there might be a risk of overestimating the true effect of the intervention. Therefore, an even larger sample size is desirable. However, feasibility also needs to be considered. In our study, 20 hours of video recordings were analysed, which was very time-consuming.

Another limitation of our study was that we only assessed student performance after their training programme. Testing their performance before, during and after training would help evaluate their performance more in depth. The focus in this study was on NTS and training NTS without measuring TS performance. To gain a better understanding of medical students' CPR performance in general, modern dummies can be used to allow the analysis of technical data, such as compression frequency or ventilation. Then, inferences about the impact of the CPR training regarding TS and NTS over time can be drawn. Future research is needed to address the interplay between TS and NTS and investigate how they influence each other. Several studies have already indicated a close link between NTS and TS (Gostlow et al., 2017; Raison et al., 2018). This relation of skills might play an important role in understanding CPR performance as a whole and should be examined carefully.

In this study, we examined medical students who were still novices in the medical domain. Fostering their NTS competences early in medical education is considered important for their professional development (Wissenschaftsrat, 2018). In this respect, our study provides insightful information about early skill development. However, competence development regarding CPR is relevant at all stages of medical education. It is a medical task related to different medical disciplines, and even health professionals have to refresh their CPR knowledge and skills regularly. Future research can compare various professionals – such as persons who are likely to be involved and responsible in CPR – and examine how they apply TS and NTS. Furthermore, a longitudinal approach with several measurement points can reveal how TS and NTS are affected over time.

In conclusion, our study has some practical implications. The intervention was short, cost-efficient and certainly feasible to implement in a medical curriculum. The goal of the CPR training was for students to learn and apply CPR procedures correctly, and be able to transfer their knowledge and skills to an analogous task. For this purpose, direct instruction as proposed by Bandura (1986) on the one hand and instructional means that foster learning from errors (e.g. Gartmeier et al., 2008; Keith & Frese, 2005) on the other seem not necessarily conflicting approaches, but complementary. In our study, we used plenary sessions to present and discuss the video among students and their instructor. It seems, although short, that the negative knowledge examples triggered the students' NTS awareness. Training NTS via mobile devices might be an even more time-efficient method. Students could watch videos as preparation and actively reflect on the displayed errors. Engaging in the simulation and being responsible for their CPR performance afterwards seems an appropriate way to learn and practise such a complex task (Burke et al., 2017; McRae et al., 2017; Sadideen et al., 2017). However, research also indicates that it is necessary to be aware of what is wrong in professional practice (Dyre et al., 2016; Gartmeier et al., 2008; Gartmeier et al., 2015). Therefore, debriefing medical students after their performance should be an integrated part of CPR training, so as to create a community in which errors are discussed openly.

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