Cognitive Aids in Acute Care:

Investigating How Cognitive Aids Affect and Support In-hospital Emergency Teams

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ABSTRACT

Cognitive aids – artefacts that support a user in the completion of a task at the time – have raised great interest to support healthcare staff during medical emergencies. However, the mechanisms of how cognitive aids support or affect staff remain understudied. We describe the iterative development of a tablet-based cognitive aid application to support in-hospital resuscitation team leaders. We report a summative evaluation of two different versions of the application. Finally, we outline the limitations of current explanations of how cognitive aids work and suggest an approach based on embodied cognition. We discuss how cognitive aids alter the task of the team leader (distributed cognition), the importance of the present team situation (socially situated), and the result of the interaction between mind and environment (sensorimotor coupling). Understanding and considering the implications of introducing cognitive aids may help to increase acceptance and effectiveness of cognitive aids and eventually improve patient safety.

CCS CONCEPTS

• Applied computing > Life and medical sciences > Health care information systems; Human-centered computing > Collaborative and social computing > Empirical studies in collaborative and social computing

KEYWORDS

Cognitive aid; Cardiac arrest; Cardiopulmonary resuscitation; Embodied cognition; Non-technical performance; Simulation

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1 INTRODUCTION

Medical crises are complex and challenging situations that require immediate management. For example, the treatment of a cardiac arrest can include chest compression, manual ventilation, and external defibrillation [59]. Combining these elements in practice is always time-critical and can thus be stressful, unpredictable, chaotic, and an emotionally demanding situation for staff [4]. Staff may be supported during crises by different artefacts that can range from aiding memory to supporting clinical decision-making [6]. One may distinguish between checklists, which are most of the time static representations in form of linear item lists and are intended to aid memory, and cognitive aids, which incorporate clinical algorithms and provide decision support [18].

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The acute care medical community shows increased interest in cognitive aids [42,43] and research showed that cognitive aids can increase technical performance in resuscitations [e.g., 15,38] and operating room crises [37]. In operation room crises, cognitive aids also had a positive effect on non-technical performance [e.g., 23,40,44,45]. However, the medical epidemiological approach provides limited insights into how cognitive aids work [33]. Indeed, the explanations of how these artefacts work can be summarized as classic cognitive psychological explanations. The artefacts are described as reducing work load [44] or freeing up mental bandwidth [21] and therefore allow staff to allocate more attention to team coordination and complex decision-making.

In the HCI community, insights on the effects of artefacts on how work is done have been reported. Sarcevic and colleagues have provided a detailed description of the use of a paper-based trauma resuscitation checklist in the emergency room [54] and the effects of the checklist on the team [65]. The paper-based checklist has also been transformed to a digital checklist [53], and usability tests [34] and in-the-wild evaluations [36] of the digital checklist have been conducted. Sarcevic et al. [54] observed that the team leader used the paper-based checklist not only as a memory aid but also noted information about the patient on the list. This indicated that the checklist also served as an artefact to externalize memory content for later use such as decision-making or documentation. Zhang et al. [65] reported that using the checklist affected the communication pattern of the team leader (an increase in communication frequency with the checklist compared with no checklist) and descriptive changes in the communication patterns depending on checklist use.

Wu and colleagues provided a thorough description of the context of medical crises and proposed [63] and evaluated [64] a dynamic procedure aid that is displayed on a large screen and controlled by a tablet computer that mirrored the content of the display. Wu et al. [64] reported that, beyond reminding staff about actions, cognitive aids focus attention on the appropriate task during crises with multiple task threads. Finally, Gonzales and colleagues analyzed resuscitation situations [19] and evaluated a collaborative cognitive aid that was projected at a wall [20]. The results of the evaluation showed that the aid was well received and that touch-based interaction outperformed gesture interaction.

In our multi-year project, we aimed to combine the medical and the HCI approach to leverage the insights into the mechanisms by which artefacts such as checklists and cognitive aids work. That is, we collected data about the effects of artefacts on clinically relevant variables but also sought to obtain insights into the mechanisms of how artefacts affect work. In the context of in-hospital cardiopulmonary resuscitations, we have developed a tablet-based application to support the team leader of in-hospital resuscitation teams to document specific events in real time – the documentation application (DocuApp). In the next iteration, we aimed at adding elements to the application to support the team leader in performing a resuscitation procedure according to the European Resuscitation Guidelines [59] – the cognitive aid application (CaApp). In the present paper, we summarized the design process of the applications with a focus on the CaApp, reported the results of a large-scale evaluation of the DocuApp vs. the CaApp in a full-scale simulation, and discussed a framework of how cognitive aids change work and increase performance.

2 APPLICATION DESIGN

2.1 Setting

The hospital under study has a central medical emergency team with rotating team members. The team consists of a specially trained senior anesthesiologist, one intensive care nurse, and a resident anesthesiologist. The senior anesthesiologist acts as the team leader and is required to document the operation in the local healthcare information system. The team is located in the intensive care unit of the Department of Anaesthesia and Critical Care. If alerted, the team can be at any hospital site within 10 minutes. At the site, the emergency team is taking over the leadership and the medical staff, who served as first responders, will support the team.

Compared to previous HCI studies, the present setting showed several differences. First, in contrast to trauma resuscitation in the emergency department [65], the emergency team has to set off immediately after being alerted and has no preparation phase. Second, the team is located in the intensive care unit but serves several units. In contrast to the summarized HCI work [19,64,65], any artefact needs to be mobile and there is no time available to set up the system at the site.

2.2 Documentation Application (DocuApp)

Good documentation, especially data of time-critical interventions during cardiopulmonary resuscitation (CPR), is important because of legal issues [39] and quality improvement. At the hospital under study, the team leader is required to enter detailed information (i.e., time of endotracheal intubation) in a user-unfriendly hospital information system after the resuscitation. The medical literature shows that good documentation can be erroneous when done from memory [60], and Gonzales et al. [19] reported that staff used paper towels for notetaking because the provided tools were not usable in fast-paced emergency situations. We developed an application to support the team leader in the real-time documentation of CPR events. Although motivated by the above reasons, such an application also provides benefits for the team leader because it reduces the documentation work. Such benefits are important because this is a benefit for the team leader and may increase the application's acceptance [64].

Using different usability methods for the context analysis and interactive design process, the final tablet-based DocuApp had a time-critical and time-non-critical mode (for details see [52]). In short, if the tablet is taken out of the docking station, the application automatically switches to the time-critical mode. This is important because the team has no preparation time and unplugging and unlocking a tablet has already been reported as challenging in settings with the pre-arrival time of the patient [35]. With one touch, the team leader can start a new resuscitation protocol, confirm when arriving at the site, and the main site of the time-critical mode is shown (Figure 1). All interactions are timestamped. In the time-critical mode, the team leader can document tasks, which have timestamps associated such as the time of intubation. In addition, there are timers for repeated actions such as defibrillation. Such support for reoccurring events is important [53,64]. After the resuscitation, the team leader can complete the documentation in the time-non-critical mode (i.e., information that does not require specific time stamps).

We evaluated the DocuApp in a full-scale simulation including real emergency teams by comparing teams that used the DocuApp vs. teams that did not use the app [22]. We observed that the DocuApp supported the emergency team leader in the real-time documentation of simulated CPR (i.e., more accurate documentation) and also enabled the team leader to document faster after the resuscitation. In addition, we observed that technical performance during the resuscitation was equal or even better when using the DocuApp than without the application. One variable, the no-flow fraction – fraction of time during the cardiac arrest when no external chest compression is performed – was even significantly shorter when using the DocuApp compared with no DocuApp. The no-flow fraction is directly related to patient outcome [8] and an important clinical variable.

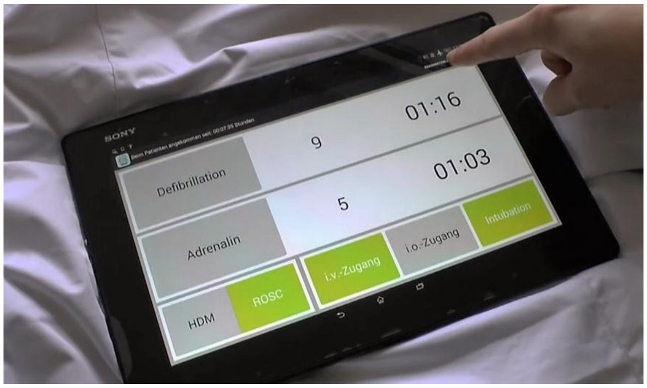


Figure 1: Time-critical mode screen of the DocuApp.

2.3 Cognitive Aid Application (CaApp)

The evaluation of the DocuApp indicated that the application also affected technical performance. Similarly, the previously mentioned trauma resuscitation checklist did not only aid memory but affected the team leader's communication [65] and decision-making processes [54]. Furthermore, we observed that, independent of application use, the teams were unsuccessful to adhere strictly to the temporal recommendations of the European Resuscitation Council guidelines. We followed a user-centered design approach and redesigned the application to foster the DocuApp's function as a cognitive aid further.

2.3.1 Cardiopulmonary resuscitation. A core part of the guidelines distributed for example by the European Resuscitation Council is the Advanced Life Support algorithm [59]. In short, for effective CPR, a defibrillator and monitoring equipment need to be attached. The patient's heart rhythm needs to be checked every two minutes and, if indicated, the patient needs to be defibrillated. This 2-minute iteration proceeds until the return of spontaneous circulation (ROSC). Interruptions of the CPR shall be reduced to a minimum. Injections of adrenaline every 3 to 5 minutes shall be given to the patient without spontaneous circulation. Amiodarone shall be administered once after the third shock for patients with persisting ventricular fibrillation.

CPR will restore and maintain blood circulation in many cases but CPR will in most cases not treat the actual cause of the cardiac arrest. Therefore, diagnosing the cause is important for an effective treatment. The reversible causes are summarized in English with the mnemonic *H's and T's* (Hypoxia, Hypovolemia, Hypo- /hyperkalemia /metabolic, Hypo- /hyperthermia and Thrombosis, Tension pneumothorax, Tamponade, Toxins). In different studies, the theoretical recall of the Advanced Life Support algorithm and H's and T's among clinicians ranged from good [41] to bad [31]. During an emergency the possible causes should be verbalized and then excluded or treated [18].

2.3.2 Context analysis. We re-used parts of the contextual analysis of the DocuApp and conducted semi-structured interviews with two experienced anesthesiologists. The gained insights were: (1) Help users to coordinate the team. (2) No need to remind users of what the Advanced Life Support algorithm is about (because the experts know). (3) Assist users in assessment of timeframes (compromised time perception during CPR [5,48]). (4) Avoid redundancy with output of other devices (e.g., compression rhythm suggested by automated external defibrillator). (5) No acoustic output (scene of emergency is often noisy). (6) Remind to consider the cause of cardiac arrest.

Interestingly, our analysis suggests to not include a visual model of the Advanced Life Support algorithm that is a core part of CPR and has been central in other applications [20,38,51]. The team leader in the current context has extensive training in CPR. Therefore, reminding the team leader of basic CPR steps would result in too much unnecessary information on the application. From this point of view, the requirements are in line with previous observations by Wu et al. [64] who report that doctors preferred clear and simple presentations instead of too much information and Sarcevic et al. [54] who suggest to adapt checklists contents to the experience level of the user. Finally, previous research also highlighted the support to keep track of timespans in reoccurring steps [20,64].

2.3.3 Prototyping. Prior to adding new features, we mirrored parts of the original interface of the DocuApp (Figure 1). Since users start looking for information in the top left corner [2], we swapped the running timers with the buttons. Right handed people, who pose a majority among users, draw an additional advantage from the buttons being on the right side. We had four iterations starting with paper prototypes and moving to fully functional prototypes implemented in Android (Google, Mountain View, CA) optimized for a 10" tablet (Xperia Z2, Sony, Tokyo, Japan, Figure 2). The final CaApp display and an explanation of the single functions are shown in Figure 3. Note that we removed the checkboxes of the *H's and T's* mnemonic in the course of the design process because we did not want to evoke the impression that a checked-off diagnosis has been ruled out and should not be considered again.

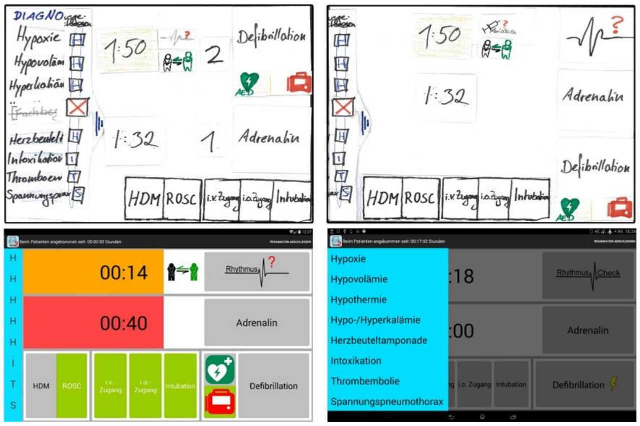


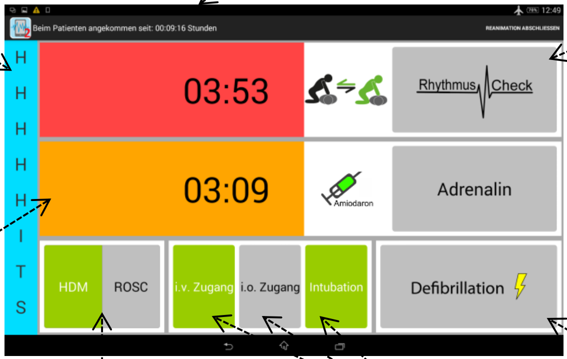
Figure 2: Different paper (top) and functional Android-based prototypes (bottom) of the cognitive aid application.

3 APPLICATION EVALUATION

Real potential emergency teams consisting of one team leader, and two additional team members, were called to a simulated emergency. The team leader used either the CaApp or the DocuApp. We evaluated non-technical and technical performance to compare the applications and contribute to the understanding of how cognitive aids work.

Previously, few studies considered real teams. Zhang et al. [65] observed in a qualitative analysis that using a trauma resuscitation checklist in the emergency department affected the communication pattern of the team leader. Marshall et al. [45] showed that the presence of a cognitive aid improved non-technical performance of teams in a simulated intra-operative anaphylaxis. However, Everett et al. [14] have observed that non-technical performance was not affected (positively or negatively) by using checklists in different simulated emergency situations of which some involved CPR. In summary, the evidence of an association of cognitive aid use and non-technical performance is mixed and not well studied.

The first aim of the study was to investigate the association between application use and non-technical skill performance in real emergency teams. Because of our positive experience with the DocuApp [22] and the user-centred design approach, we expected a positive association between application use and non-technical performance. The second aim was to compare the effect of application type (CaApp vs. DocuApp) on technical performance. Based on the added elements in the CaApp, we expected better technical performance with the CaApp compared with the DocuApp. The third aim was to investigate the association between technical and non-technical performance and application use.



The bar shows the German version of the Hs and Ts mnemonic. If touched, the bar expands to 1/3 of the screen and shows the Hs and Ts. The colour of the bar pulsates after each documented rhythm analysis or adrenalin injection when no other warnings are present.

Elapsed time since arrival at patient.

Button to document a heart rhythm analysis. Pressing the button resets the time on the left. The timer shows the elapsed time since the last documented rhythm analysis. The background turns orange after 1:40 minutes. In addition, the icon indicates to prepare to change the person who is providing the chest compressions. The timer turns red after 2:00 minutes.

Button to document adrenalin injection (on the right). Timer on the left indicates elapsed time since last documented adrenaline administration. The background turns orange after 3 minutes and red after 5 minutes. Syringe icon appears after the 3. defibrillation to remind to consider amiodarone administration.

Toggle button to indicate either cardio pulmonary resuscitation or return of spontaneous circulation. Green background indicates the current selection.

Buttons to document i.v. or i.o. line establishment and intubation. Green background indicates that the intervention has been documented.

Button to document defibrillation.

Figure 3. Final CaApp design and explanations of the single functions. The screenshot was made for demonstration purposes only.

3.1 Method

3.1.1 Participants. Ethical approval for this study was provided by the Ethical Committee at the Medical Faculty of the University Hospital Würzburg, Germany. Written informed consent was obtained from all participants. Without previous knowledge of which anesthesiologist or other staff would be available for a specific session, we determined which session included the CaApp or the DocuApp. Anesthesiologists participated depending on their work schedules.

Because the data collection was piggybacked on to full-scale simulation CPR trainings, we were only able to collect the data of 36 team leaders. Three data sets had to be excluded because one team leader forgot to bring the tablet, one team leader placed the tablet on a shelf and did not interact with the tablet at all, and during one scenario the application crashed. Finally, due to technical failure, the video of one team in the CaApp group could not be analyzed for non-technical performance. We observed no significant differences in the demographics of the team leader between the CaApp group (n=17, M_{age}=35 years, $M_{work\ experience}$=7.25 years) and the DocuApp group (n=16, M_{age}=36 years, $M_{work\ experience}$=6.25 years, p=.790 and p=.924).

3.1.2 Procedure. The study was conducted at the local simulation center, using a *Resusci Anne Simulator®* (Laerdal, Stavanger, Norway). We used two scenarios, both including a cardiac arrest, albeit for different reasons (scenario 1: hypovolemia, scenario 2: asphyxia; see supplementary materials for scenario descriptions). On each day of the study period, we conducted two sessions (morning and afternoon), and each session included both scenarios. The application condition was counterbalanced in relation to the time of day. The emergency team always consisted of a team leader (a senior anesthesiologist with qualifications in emergency medicine and intensive care medicine) and two additional team members (one nurse with qualifications in intensive care medicine and special training in CPR and an anesthesia trainee). Three other participants pretended to be ward nurses or other staff members as part of the scenario.

All participants received a short introduction to the simulation environment. The team leader received 3 minutes of training to become familiar with the respective application. Our previous study [22] showed that such a brief training was sufficient to use the application effectively. For both applications, participants were instructed to document as many actions and interventions as possible (start time of CPR, defibrillations, etc.). After the training, the tablet was placed in a docking station. The emergency team waited outside of the simulation room until a member of the simulation team placed the emergency call via phone. After the scenario, the team leader answered a questionnaire including demographics and a workload measure.

3.1.3 Measures. To investigate non-technical performance, one blinded reviewer (an anesthesiologist from a different hospital with 7 years of work experience and 10 years of simulation training experience who did not know the participants of the study) watched the recordings and rated the teams' performances using the Team Emergency Assessment Measure (TEAM), a measurement instrument specifically developed for medical emergency teamwork [10,11]. We aggregated the TEAM questions 1 to 11 and used the percentage of the maximum TEAM score as the dependent variable. In addition, the reviewer rated how frequently the team leader used the tablet on a scale from 0 (never/hardly ever) to 4 (always/nearly always).

To investigate the technical performance, we followed the approach of previous research [37,46] and calculated a technical performance score in percentages. We analyzed 10 (hypovolemia scenario) and 9 (asphyxia scenario) variables and assigned either 0, 1, or 2 points (Table 1). The variables and the scoring were based on the information of the European Resuscitation Council guidelines [59].

The no-flow time was defined as the time of cardiac arrest in which no chest compressions were being performed. We did not count a pause in chest compressions shorter than 1 second as CPR interruptions. The no-flow fraction was the ratio between no-flow time and the total time of cardiac arrest at which the emergency team was present (i.e., team entered the simulation room until return of spontaneous circulation). The time to the first heart rhythm analysis/defibrillation was defined as the time of arrival at the patient until the first rhythm analysis/defibrillation. For chest compression depth and rate, no-flow fraction, and time to first rhythm analysis/defibrillation calculations, we used the data recorded by the patient manikin (*SimPad*®, Laerdal, Stavanger, Norway). For guideline-conform changes of the helper (i.e., the person providing chest compressions), adrenaline administration, and heart rhythm analysis, we extracted the time intervals between each of the specific actions, starting with the first event. We subtracted these intervals by 2 minutes for the change of the helper and heart rhythm analysis, or 3 to 5 minutes for adrenaline administration, depending on whether adrenaline was administered too early (before 3 minutes had passed) or too late (after 5 minutes had passed). We also measured the time until diagnosis-related actions were performed (hypovolemia: order a blood gas analysis, asphyxia: assess the location of the tracheal tube). Finally, we assessed the workload of the team leader using the NASA TLX [24]. Each of the six sub-scales was rated on a 20-point Likert-scale, and we report the average of all six sub-scales.

We coded the number of diagnosis-related statements from the team leaders (see supplementary materials for coded statements). Furthermore, we coded each time the team leader engaged in a manual task that could have been done by other staff members (e.g., drawing up a medication) and calculated the relative proportion of time of such hands-on activities (see supplementary materials for coded activities).

3.1.4 Analysis. The data were analyzed using parametric tests or non-parametric tests if the dependent variable was not normally distributed based on a Kolmogorov-Smirnov test. We used Pearson's correlation (r) for parametric data and Spearman's rho (r_s) for categorical data. The statistical analysis was conducted using IBM SPSS Statistics for Windows, Version 24 (Armonk, NY: IBM Corp). Alpha was set at .05 and all reported p-values are two-sided.

3.2 Results

We observed a positive correlation between the TEAM score and application use (r_s=0.525, p=.002, Figure 4). A correlation between the ratings on application use and the objectively logged interactions with the application validated the expert rating (r_s=0.419, p=.017). When comparing the applications, we observed no difference between the TEAM score in the CaApp group 73.3% (SD=12.7) and the DocuApp group 68.9% (SD=23.4, p=0.515). The CaApp (Mdn=2, IQR=2) was used more frequently by the participants than the DocuApp (Mdn=1, IQR=2, p=.021; scale ranging from 0 =never/hardly ever to 4=always/nearly always).

We observed no difference in the technical performance score between the CaApp group (M=40.8%, SD=15.4) and the DocuApp group 33.7% (SD=10.8, p=0.140; see also Table 1). We observed no significant correlations between the technical performance score and the TEAM score (r=0.137, p=0.455) or application use (r_s=0.061, p=0.739).

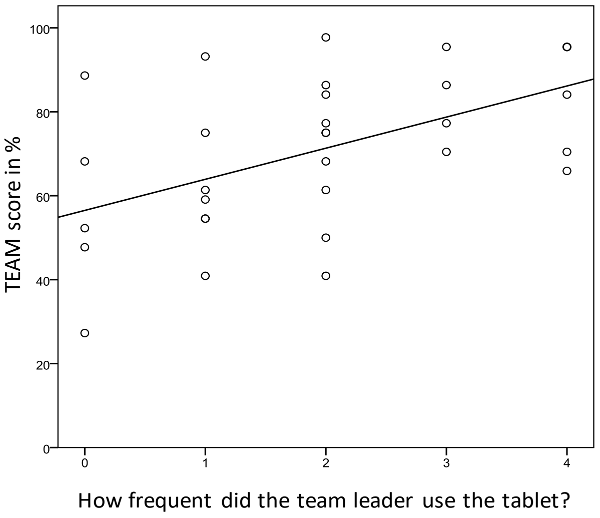


Figure 4: Correlation of TEAM score and application use.

Finally, we observed no significant difference in subjective mental workload between the CaApp (M=6.18, SD=0.94) and the DocuApp (M=5.81, SD=1.30, p=.368; scale ranging from 0=lowest possible rating to 20=highest possible rating).

The CaApp group made 113 and the DocuApp group made 102 diagnosis-related statements. The visual inspection of Figure 5 indicates that the CaApp group started to make diagnosis related statements earlier. More diagnosis-related statements were significantly associated with higher TEAM scores (r_s=0.533, p<.002) but only descriptively with frequent application use (r_s=0.277, p=.125). There was no association between diagnosis-related statements and technical performance scores (r_s=0.031, p=.865).

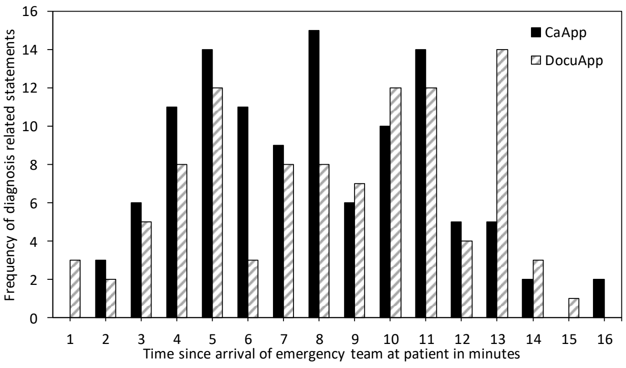


Figure 5: Absolute frequency of diagnosis-related statements.

The average hands-on time was 22.6% (SD=16.2). There was no difference between the CaApp group (M=23.9%, SD=20.3) and the DocuApp group (M=21.3%, SD=11.4, p=0.655). Less hands-on time was significantly associated with more diagnosis-related statements (r_s=-0.356, p=.045) and more application use (r_s=-0.491, p=.004). Hands-on time and the TEAM score (r_s=-.269, p=.136) and the technical performance scores (r_s=-.161, p=.380) were descriptively associated.

Table 1. Description and results of technical performance scoring. Values indicate frequencies.

Variable		Scores		
		0	1	2
No-flow fraction (%)		>20	20-15	<=15
	CaApp	1	1	15
	DocuApp	0	2	14
Average chest compression depth (cm)		other	-	5-6
	CaApp	13	-	4
	DocuApp	15	-	1
Average chest compression rate (min^{-1})		other	-	100-120
	CaApp	7	-	10
	DocuApp	5	-	11
Time to first heart rhythm analysis (s)		>138	121-138	<=120
	CaApp	7	3	7
	DocuApp	12	0	4
Time to the first shock (s)$^{+}$		>138	121-138	<=120
	CaApp	4	1	4
	DocuApp	4	0	3
Deviation from helper change algorithm (s)		>36	19-36	<=18
	CaApp	6	6	5
	DocuApp	9	1	6
Deviation from adrenaline algo. (3-5 min)		other	-	0
	CaApp	15	-	2
	DocuApp	13	-	3
Deviation from heart rhythm algorithm (s)		>36	19-36	<=18
	CaApp	11	4	2
	DocuApp	12	4	0
Amiodarone administration $^{+}$		None	Given	3rdshock
	CaApp	4	2	3
	DocuApp	4	2	1
Time until order of blood gas analysis (s)		>180	121-180	<=120
	CaApp	14	2	1
	DocuApp	14	1	1
Time until tracheal tube assessment (s)*		>180	121-180	<=120
	CaApp	4	1	3
	DocuApp	6	2	1

$^{+}$Only hypovolemia scenario, *Only asphyxia scenario

3.3 Discussion

Consistent with the qualitative results of Zhang et al. [65] and the quantitative results of Marshall et al. [45], we observed the expected positive association between application use and non-technical performance. The absence of such a positive association in the study of Everett et al. [14] has been attributed to the measurement tool, which was not validated for their context [43]. We used the same tool (i.e., the TEAM score), albeit on CPR scenarios for which the tool was developed [10,11]. Finally, our results are also in agreement with recent studies on various operating room crises, which reported a significant positive association between individual (i.e., only the team leader was a participant and the other team members were actors) non-technical performance and cognitive aid use [e.g., 37,40,44].

We did not observe the expected significant advantage of the CaApp vs. the DocuApp in relation to technical performance. Because the DocuApp already improved technical performance [22], the present baseline against which we evaluated the CaApp may have been already very high. This argument may be supported by the very low no-flow fractions in the present study (29 out of 33 teams achieved a no-flow fraction of <15%) compared with our previous study (with DocuApp 16.91%, without DocuApp 22.44%, [22]) and other research on emergency teams such as real in-hospital adults CPR (24%, [1]) or simulated CPR (25%, [47]). The very low no-flow fractions may be due to highly qualified participants and the uptake of the 2015 CPR guidelines [59] that further emphasizes the importance of uninterrupted chest compressions.

Although studies showed a positive association between technical performance and non-technical performance [55], the present results provide only descriptive evidence for such an association. Similarly, in the context of cognitive aid research, recent studies have reported a significant positive association between team [45] and individual [44] non-technical performance and the use of a cognitive aid, but only descriptive beneficial effects for clinical performance during different simulated crises in the operation room. At present, we can only speculate why this is the case. First, the benefits may be small and previous and our study may have been underpowered. Second, non-technical performance may only be related to specific performance measures and not to performance scores. Third, the effect of non-technical performance on technical performance may only arise in specific situations such as very challenging events.

Our study has several limitations. First, we assigned the application condition to specific times and staff participated depending on their work schedule. Therefore, the comparison between the different applications was not experimental because it did not include full random assignment. Second, for the quantitative application comparison, an a priori power analysis on the main outcome variable would have been appropriate [7]. Third, interrater reliability has been an issue when using the TEAM score to measure non-technical performance, and we only had one rater. However, in contrast to a previous study [14], our scenarios included only CPR, for which the TEAM measure has been designed [11]. In addition, the rater was blinded to the application condition because every team leader used a tablet. Finally, the coded application use and the objectively logged interactions with the applications showed a strong positive correlation.

In summary, the results of the present study provide evidence for a positive association between electronic cognitive aid use and non-technical performance during simulated in-hospital CPR. Cognitive aids seem to be a promising way of supporting clinicians in challenging crisis situations; however, as noted by Marshall [43], more studies on the relationship between (different versions of) cognitive aids, non-technical team performance, and clinical performance are needed.

4 FRAMEWORK FOR THE EFFECTS OF COGNITIVE AIDS IN ACUTE CARE CRISIS

The presented results, among other things, no differences between the applications in terms of technical performance. The results answer the epidemiological question ‘does it work?’ In relation to technical performance, the cognitive aid application did not improve performance, in comparison with the documentation application. However, the question provides only limited understanding of how cognitive aids work. Building an understanding of how cognitive aids work is important; otherwise, the research is on a trial-and-error basis.

Considering the healthcare literature, we are not aware of an explicit or more comprehensive explanation of how cognitive aids work [cf. 33]. Recent medical publications have provided practical frameworks [e.g., 6,17] for the design of cognitive aids such as context analysis, examining the purpose of the aid, presentation modality, etc. However, these have fallen short of addressing theoretical explanations. In final section, first, we summarize how the effects of cognitive aids are explained in the healthcare domain. These explanations can be summarized in terms of the classic information-processing view. Second, we suggest a framework, based on embodied cognition, for understanding the effects of cognitive aids in acute care settings. Third, we consider how this framework may contribute to the design of future cognitive aids or healthcare information technology in general.

4.1 Classic Information-Processing View

In the medical literature, cognitive aids have been described in a classic information-processing view. Cognitive aids assist memory and reduce workload [44] or free up mental bandwidth [21] and therefore allow staff to focus more attention on team coordination and complex decision-making. Sarcevic et al. [54] considered checklists as memory externalization tools. By referring to distributed cognition [28,29], Sarcevic et al. expand the unit of analysis beyond the team leader's individual cognition and considered the team leader and the list as the unit of analysis. However, at the core, the checklist is still considered as tool that prompts or aids memory of the artefact user (Figure 6). Such an explanation seems unsatisfying for several empirical and theoretical reasons.

First, despite informal feedback by the participants, that the applications were good memory aids, the workload measure in the present study showed no differences between the DocuApp and the CaApp even though the latter included more reminders and was used more frequently. Similarly, Parsons et al. [50] reported no differences in subjective workload between a trauma resuscitation checklist group and the no checklist group.

Second, prospective memory research – the research on how humans remember intentions at the right time in the future – suggests that, if good environmental cues are provided, such as in the form of checklists, the cognitive costs of remembering to remember are very small [58] or there are no costs at all [57]. Considering the prospective memory literature, the aforementioned workload findings do not seem surprising.

Third, checklists and cognitive aids affect physical behavior and communication. In the present study, frequent application use was associated with more diagnosis-related statements and less hands-on time. Similarly, Zhang et al. [65] reported that instruction on how to use a checklist changed the interaction style of the team leader. In particular the comparison of two applications (e.g., the present study) and one checklist with different user instructions [65] challenges a classic information-processing view on artefact use in acute care.

Fourth, the idea that checklists are followed in a linear, sequential order and all steps can be read off the list applies to settings with lower time-pressure and enforced checklist use such as during take-off in aviation. In routine cases, a strong emphasis on the memory aid aspect of checklists seems appropriate. However, as Burian et al. [6] note, in acute care, checklists are used in a sample-fashion. That is, the checklist is not followed in a linear fashion but the procedure may be started and the artefact is only consulted later or sampled in between actions. This observation highlights that attention is an important mechanism in the use of cognitive aids. Indeed, Wu et al. [64] make the point that cognitive aids need to allocate attention to the appropriate task at the appropriate time. Different from routine checklist use, where actions are checked-off as completed, the time-pressure, the patient case, and the team determine the use of the artifacts [54].

Figure 6: Information-processing view: only cognition of the team leader is affected by application.

4.2 Embodied System View

We first describe the implications of taking a system view. Then, in order to understand the effects of checklists and cognitive aids on the user, we suggest an embodied cognition approach [9,13]. As a reference, we use the three perspectives to embodied cognition suggested by Van Dijk et al. [62]: the distributed perspective, the socially situated perspective, and the sensorimotor coupling perspective.

4.2.1 The system view. 'Taking a systems view' is generally considered to study the user in the actual context of the task including other human and non-human agents and the whole environment that may influence behavior [27]. In the context of emergency situations in acute care, such as the scenarios in the present paper, this includes the patient, the other team members and further staff, technological and non-technological equipment, and other resources. The actual boundaries of such an activity system need to be determined by the researcher or designer who needs to decide whether there is sufficient connectivity between a specific agent and other elements in the system to include this specific agent in the analysis [25,30].

4.2.2 The distributed perspective. The distributed perspective considers human and non-human agents in the system and analyses the information flow between the agents. In short, the information-processing approach is extended to a larger activity system. For example, Sarcevic et al. [54] described a checklist as an externalized memory.

Introducing an artefact into an activity system, however, has more severe implications. First, the task of the individual who is using the artefact changes [49]. For example, without a checklist, a clinician has to remember all necessary task steps from memory, which can be considered as a retrospective memory task. With a checklist, the clinician has not to retrieve the steps from memory but allocate attention to and read off the checklist. The former memory task is replaced by a reading task.

Another example is the heart rhythm analysis check every two minutes. Without the CaApp, the team leader has to remember the time of the current heart rhythm check, monitor the timeframe for approximately two minutes or calculate the time for the next check, and remember to initiate the next check at the appropriate time. With the CaApp, if the tablet is held in one hand, the team leader needs to document the current heart rhythm check, notice the color change on the tablet or the vibration of the tablet at 1:40 or 2:00 minutes after the initial check. In this case, a prospective memory task is changed. The resulting task has a much larger perception component.

Second, the system's output changes. Ideally, introducing a cognitive aid improves technical or non-technical team performance and eventually improves patient outcome.

In light of the distributed perspective, the unit of the analysis changes from a team leader-cognitive aid dyad to a larger activity system consisting of human and non-human agents. The system, however, can still be analyzed using a cognitive approach [28], i.e. information manipulation and transition between agents, and the cognitive tasks of the team leader changes [49] (Figure 7).

The distributed perspective offers an explanation for why artefacts result in more guideline conform processes [50], but also provides an explanation for why a different version of a checklist with the same content results in a different performance. For example, Ramachandran et al. [51] investigated the effect of artefact design on the identification of the correct reversible cause in a cardiac arrest scenario. A context sensitive cognitive aid required from the user to assess several medical symptoms whereas an alphabetic cognitive aid simply showed the causes in alphabetic order. The medical content of the two versions was the same.

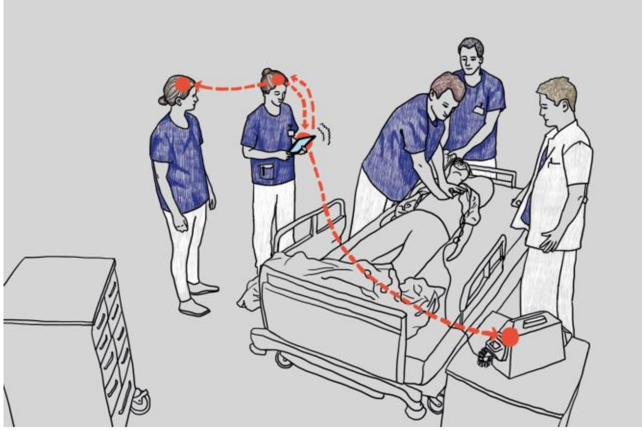


Figure 7: Distributed perspective: information transition (dashes lines) and information manipulation (dots).

Because the medical performance (i.e., systems output) was the same, one may have the impression that both versions acted as 'memory aids'. However, the designs of the aids resulted in two very different cognitive demands for the team leader. The context sensitive version required more user input and significantly longer interaction times compared to the alphabetic version.

4.2.3 The socially situated perspective. The socially situated perspective emphasizes the specific circumstances of a situation and the actual options for action in this situation [61]. In the context of acute care, the perspective highlights that the team leader has received training, is experienced in crisis management, and therefore has a 'plan of action', but that each crisis is very unique and the specific patient case, environmental circumstances, and so on immediately affect that plan and require or result in adjustments. Similarly, artefacts influence the plan and actions. From a socially situated perspective, checklists and cognitive aids shape how work is done and therefore stress the coordination of work.

The socially situated perspective can help explain the effects of a sample-fashion use [6] of artefacts in acute care. That is, the situation has a stronger effect on the actions of the team leader than the plan provided by the checklist. Importantly, it is probably impossible to make a general statement whether the intended plan suggested by the checklist or the actual actions result in a better patient outcome. On average, the checklist should result in a better outcome, because the content is based on the state-of-the-art literature. However, in one of the scenarios, the automated external defibrillator was already set up and connected but not in use. Making use of this situation would have resulted in a faster first check of the heart rhythm.

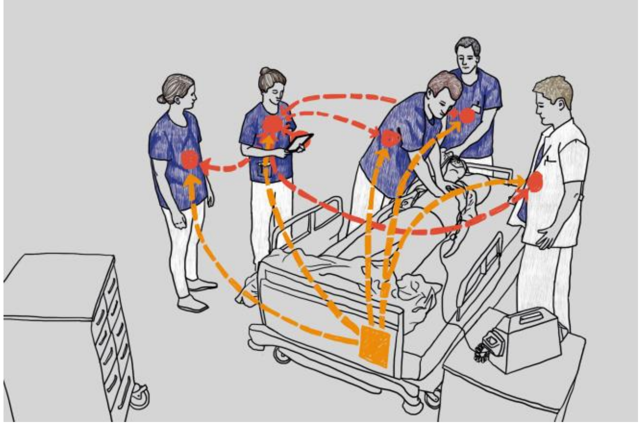


Figure 8: Socially situated perspective: application affects team via team leader behavior and bed location affects staff behavior.

In such a case, using the situational circumstances as encountered would result in improved performance. Another example is the rearrangement of the environment. In one scenario, the patient's bed was located in the corner of the room. Many (but not all) teams moved the bed out of the corner to get better access to the patient.

The socially situated perspective highlights the situatedness of action and the active component of artefacts for work organization [62]. The applications in the present study are such an artefact that also may have affected the actions of the team leader. For example, frequent application use was associated with more diagnosis-related statements and less hands-on time. Critically, different to the classic information-processing view, the effects of the applications did not only affect the cognitive processes of the team leader but changed work coordination and therefore affected the whole team (Figure 8).

4.2.4 The sensorimotor coupling perspective. The sensorimotor coupling perspective considers that our actions and behavior influence how we perceive the world around us. This tight connection between action and perception highlights that 'sense-making' is not only something that happens in an individual's brain but also in the physical world around us [62].

In acute care crisis, staff frequently want to get hands-on, contribute, and 'do something to help'. Such involvement can make it hard to stay on top of the global situation – so-called situation awareness [56] – and can result in fixations errors [16]. By holding a physical artefact, the team leader is forced to not engage in manual hands-on tasks. In such a situation, tasks are delegated and communication and coordination becomes more important.

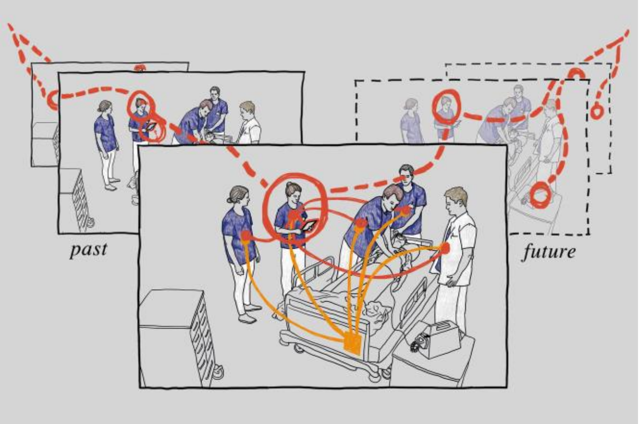


Figure 9: Sensorimotor coupling perspective: application affects team leader behavior and behavior affects sense-making.

The sensorimotor coupling perspective highlights the effect of the continuous interaction with the environment in the process of creating meaning or situation awareness (Figure 9). The positive association of cognitive aids use and non-technical performance in the present study and previous studies [45] may well be due to holding the artefact in the hand and disengaging from the manual operations and focusing on higher level activities [32].

4.3 Implications of an embodied system view

Finally, we discuss the design possibilities for cognitive aids and other healthcare information technologies taking an embodied system view. First, Van Dijk et al. [12,62] provided four general "entry-points" for the integration of technology (so-called coupling) into the loop of existing work to support, in particular, socio-sensorimotor integration. For example, the entry point *trace* relates to the traces left by people's actions, which may act as a guide for further actions.

The already connected automated external defibrillator (section 4.2.3) can be considered as a 'trace' in its capacity of guiding the action of the team leader. The defibrillator could be modified to encourage the team leader to pick up this trace in their socio-sensorimotor loop. Alternatively, the tablet application could support the entry-point *sense-to-act* by enabling team leaders to sense the connected and ready-to-use defibrillator. For example, the tablet application could highlight the defibrillator, using augmented reality. The general idea of entry points is to fluently integrate social or physical elements of the environment in the sense-making and action loop of an individual.

Second, in relation to the distributed perspective, the design could consider how an artifact changes the cognitive processes of the user or the whole team. As illustrated above (section 4.2.2), introducing an artefact such as a cognitive aid can change the cognitive task of an individual profoundly. This insight is also relevant for other healthcare information technologies, such as those of electronic health records. Introducing, for example, electronic anesthesia protocols allows for the automatic documentation of vital signs or blood gas analysis results. The anesthesiologist need only to acknowledge new values, by clicking on respective buttons on the computer monitor, where previously the values had to be noted on paper or entered in charts. In the latter case, the information has to be actively processed and, in the case of charts, related to previous values – which may have increased the understanding of trends. Cognitive ethnography (e.g., [3]) is a good method for studying cognitive processes between agents (human and non-human) in a system.

Third, in general, consideration of different theoretical views affects what one considers important in the design. Hornbæk and Oulasvirta [26] recently summarized various concepts of interaction and made the point that the different concepts work as a thinking tool. Taking an embodied system view (but also other concepts of interaction, see [26]) is likely to highlight novel aspects in the design process of cognitive aids or other healthcare information technology.

5 CONCLUSION

There is a persisting need to support clinicians during fast-paced and stressful, emergencies such as in-hospital resuscitations [1]. Artefacts such as checklists and cognitive aids can provide such a support [42]. So far, the medical community focused on the effectiveness of cognitive aids in relation to medical outcomes and the HCI community focused on describing the use of such artefacts. We summarized our multi-year research program on technological support during in-hospital resuscitations and, based on the literature and our own results, suggested embodied cognition as an approach to understand the multiple effects of checklists and cognitive aids. We believe that considering the distributed, socially situated, and sensorimotor coupling perspectives can provide a basis to understand how cognitive aids work, provide insights in the design of supporting artefacts, and eventually help to improve patient safety.

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