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RESEARCH REPORT

EXAMINING WORKFLOW FOR SIMULATED PEDIATRIC EMERGENCY MEDICAL SERVICES CARE

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ABSTRACT

Purpose: The purpose of this study was to characterize emergency medical service (EMS) workflow in the care of children during simulated emergency, prehospital encounters.
Methods: This is a secondary analysis exploring high-fidelity videorecorded simulations, performed by EMS personnel. Two scenarios were used in 19 simulations which consisted of a 15-month and a 1-month-old with respiratory decompensation and shock requiring intravenous fluid, respiratory support, and medication administration. One trained investigator performed reviews of the videos of teams EMS practitioners, quantifying the sequence and number of tasks performed and time to completion of the simulated intervention. The variance in sequence of tasks was quantified using the Levenshtein distance. We quantified the proportion of time with no activity (idle time) and temporal overlap (team multitasking time).
Results: We identified 17 types of distinct tasks performed during the simulation. There was high variability across simulations in the sequences, types, and number of tasks performed. The number of team members involved in each video varied, ranging from three to six. Activities were frequently accomplished by one or two people, but sometimes these activities could require three. Team multitasking was noted in all scenarios, with a mean of 99% multitasking ratio (range: 52-202%). Mean proportion of idle time was 4% (range: 0-11%). Weight estimate, intravenous or intraosseous access (IV/IO), radio report, blood glucose level (BGL), medication administration, pulse check, and respiration check were observed in all videos. Other tasks were observed in only a proportion of scenarios with varying frequencies. The median number of differences in sequence of tasks between scenarios was 15.
Conclusions: We were able to identify many of the tasks used by EMS personnel and the duration of time to complete such tasks. This method of identifying and quantifying EMS tasks may be useful in workforce allocation, identifying strengths and weaknesses of team members, or evaluating a team member's readiness for the field.

INTRODUCTION

Workflow is a central concept in studying health systems and care delivery (Ozkaynak 2016). Understanding workflow is particularly important in designing, implementing, and evaluating systematic interventions to improve patient and organizational outcomes (Ozkaynak 2016). Although workflow studies are common in clinic and hospital settings (Ozkaynak 2016, 2019, 2018, 2015), workflow in the domain of Emergency Medical Services (EMS) has not been fully explored.

EMS practitioners face challenges in their work due to uncertainties related to the type of patient, the environment in which they find themselves, and the pressure of responding rapidly. These factors could significantly affect the quality and safety of patient care in the field (Kaufmann 2020). Systematic informatics interventions, such as clinical decision support (CDS), may overcome some of these challenges (e.g., determining when and how to perform a certain procedure or treatment), however, understanding EMS workflow is an essential first step in developing such intervention (Ozkaynak 2016, Ozkaynak 2020, Zhang 2020). Workflow analysis for EMS practitioners can reveal many details of work such as, what activities are conducted, who is involved, and the temporal relationship of activities during an encounter. These details can inform the design, implementation and evaluation of systematic interventions that could improve the quality and safety of EMS care and ensure that the intervention is congruent with workflow.

The examination of EMS workflow is inherently challenging given the diversity of patient events and work environment. Traditional methods such as in situ observations or interviews, may not be feasible or effective to capture the subtle details of EMS workflow, given the infrequent occurrence of certain types of encounters, such as pediatric emergencies. Simulation, a common training method for emergency care and other providers (Hayden 2018), can be a valid and efficient way to recreate high risk events in a low-stakes environment and therefore can be a beneficial approach in capturing EMS workflow. Simulation also allows for a control of the environment, allowing for exploration of human factors and complexity in clinical care. Specifically, simulations of pediatric emergencies allow for the study of many critical events, such as the temporal sequence of events, that would otherwise be difficult or impossible to capture in a reasonable timeframe in "real world" settings given the low frequency of pediatric EMS encounters. The purpose of this study was to characterize workflow for EMS care during simulated pediatric emergencies, a low frequency, high-risk event in the out-of-hospital setting. We defined workflow as the sequence of performed activities and amount of time utilized to provide care to a patient by an EMS team (Ozkaynak 2019).

METHODS

Study Design

This is a secondary analysis of a series of videotaped simulation conducted within a single EMS agency in the mountain region of the U.S. The simulations from the parent study were recorded in a 6-month period from September 2018 to March 2019 (Kothari 2020). The study investigators obtained IRB approval from the Colorado Multiple Institutional Review Board (COMIRB) through a secondary data analysis IRB application.

Study Participants

Participants were licensed EMS providers from one local EMS agency that served a population of 280,000 over 130 square miles. All participants were trained and certified with either Pediatric Advanced Life Support (PALS) or Pediatric Emergencies for Prehospital Providers (PEPP). All participants were active EMS and fire professionals that routinely respond to emergencies and met the state licensure requirement for their scope of practice and employment. The participating EMS agency routinely conducts mandatory quarterly education, designed to train on updated protocols and new clinical initiatives undertaken by the agency. The last series of pediatric trainings were conducted a year before these simulations and were part of a clinical initiative to introduce a new medication dosing program for children.

The teams of EMS practitioners participated in the simulations consistent with their typical composition when responding on scene. In general, teams were comprised 1-3 paramedics, and 1-3 EMT and AEMTs. Participation in simulation training took place at a central training center during the EMS professionals' scheduled shifts as part of their mandatory quarterly education. Individual stations went out-of-service to participate with their crews. Investigators of the parent study did not control for team composition.

Simulations

A random selection of videotaped simulations conducted as part of a separate educational study were reviewed and analyzed. We utilized the simulations conducted in the first part of the educational study (i.e., within the first 3 months) to capture baseline EMS workflow associated with a pediatric emergency. High-fidelity simulations consisted of two scenarios: a 15-month child with hypotensive shock and seizures and a 1-month old infant with hypoglycemia and shock, both requiring intravenous (IV) fluid, medication administration, airway management, and treatment of hypotension. In the scenario with hypoglycemia, the mannequin was set to have seizure activity if not treated with dextrose within 5 minutes of the simulation starting. The scenarios were constructed with expected activities based on the agency's EMS protocols. The content was identified to generate recognition and appropriate management of shock and respiratory failure. The "patient" was a high-fidelity pediatric mannequin with real-time tactile and auditory feedback. The simulation attempted to mirror standard paramedic practice. Each scenario was conducted with a high-fidelity mannequin made by Laerdal (TM). Two separate mannequins were used, one the size of an 18-month-old and one the size of a 1-month-old. The mannequins were controlled by a remote tablet that could change both an electronic monitor as well as sounds and tactile findings (i.e., pulse). The fidelity of the mannequins included pre-recorded verbal responses, cardiac sounds including a gallop, murmur, and rate; respiratory sounds including stridor, wheezes, rhonchi, and rales; pupillary changes including fixed, responsive, and unequal; facial coloring to indicate cyanosis; changes in tongue size; and motor activity such as seizure. The mannequin operator was present in real time watching the scenario and would indicate when an action was completed, thus resulting in an automatic change in vital signs or other high-fidelity simulation activity accordingly. The same computer operator ran all 135 scenarios in the parent study.

The EMS teams used their own training equipment organized in the manner of their own pediatric bags used in the field. They also had a mock drug box for use of controlled medications such as midazolam. The teams were provided with bags of crystalloid and ampules of dextrose that were the same as those used by the agency. The teams were oriented to the mannequin with the ability to assess heart and lung sounds, feel the tactile components (pulse, tongue size) and see the motor changes such that they could recognized these features during the scenario. The pre-briefing took 15 minutes and was conducted immediately prior to the simulation scenario. The simulation was conducted in a mock ambulance interior environment outfitted with cameras and microphones. Events and scripts were standardized, with changes in patient condition occurring at pre-determined intervals. Teams were asked to provide normal care following their protocols as they would in the field. This included a primary assessment with vital signs, oxygen administration, ventilatory support, intravenous or intraosseous access, and fluid and medication administration. Figure 1 shows an exemplar of the scenario timeline.

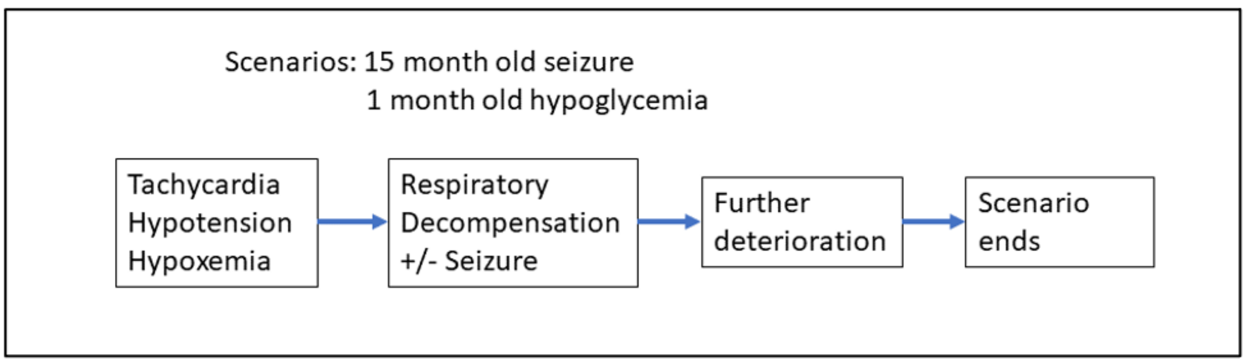

Figure 1. Projected Simulation Sequence

Data Analysis

All prerecorded videos (simulations) were reviewed by one of the authors (CD) for workflow analysis. The reviewer had prior EMS experience and was trained on analysis by an author (MO) with expertise in systems engineering and health informatics. The reviewer was instructed to review each of the videos and the videos were replayed as needed. The following outcomes were noted: activity type, time from the start and completion of the activity (time on task by the team), the provider(s) involved in each activity, and video duration.

We report on three building blocks of workflow: activities, roles, and sequence, as suggested in patient-oriented workflow approach (Ozkaynak 2019). Activities were defined as distinct tasks performed by one or more members of the team. We defined these activities after the simulations were video recorded but before observer watched the videos. Frequency of each activity performed during the simulation was captured along with the time at the start and at the completion of the activity. For activities that were repeated during the simulation, the number of times it was performed was captured by the video reviewer. We defined 'idle time' as the proportion of time when no recorded activity was being conducted. Non-idle time was the total time when there was at least one activity being recorded during a simulation. We defined team multitasking as simultaneous engagement in more than one task by team members and calculated team multitasking ratio. This was determined by the difference between the total video (e.g., simulation) time and the non-idle time divided by the non-idle time. We used this metric given its ease of interpretation. This metric shows the ratio of the time of multitasking when any activity was being conducted. If the score was 0% it meant there was no multitasking, indicating that the team was conducting only one task. If the score was 100% then it meant, on average, there was one additional task (a total of two activities) performed during the non-idle times throughout the simulation. Multitasking in this study was not an indication that multiple people were involved in the same activity, but instead denotes that two or more distinct activities were conducted simultaneously by the team.

For role analysis, we reported on the number of people involved in each scenario and in their steps. For the analysis of sequence, we utilized the Levenshtein distance (a string metric). The Levenshtein distance has been used in examining workflow in emergency departments (Ozkaynak 2012). Specifically, the Levenshtein distance is the number of changes in one string that is needed to create a new string. These changes could include a different order of elements or the addition and subtraction of different elements. In our analysis, we first coded each activity by a letter and then ordered the sequence of activities for each scenario thus creating a word for each simulation. We then calculated the Levenshtein distance (Pentland 2013) to identify the minimum number of changes in each simulation activity sequence (the corresponding word) required to match one simulation to another. A pairwise comparison matrix between each simulation was performed. We report the median Levenshtein distance with the interquartile range (IQR) between each pair of simulations over the total number of comparisons. Figure 2 illustrates an example of how Levenshtein distance is calculated.

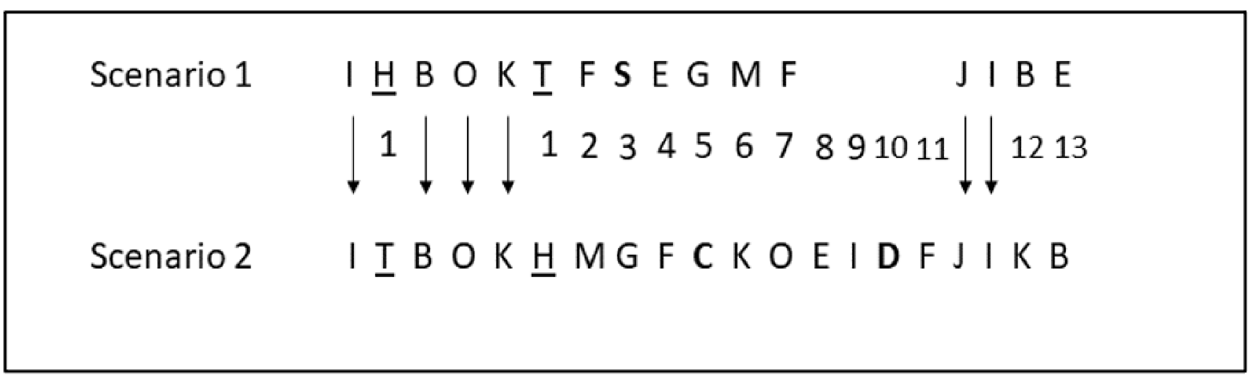

Figure 2. Illustration of Levenshtein distance calculation. In this hypothetical example, the workflow for scenario 1 could be converted to scenario 2 in 13 steps. The underlined activities of scenario 1 (H and T) can be replaced to match scenario 2. Therefore, Scenario 1 can be matched to Scenario 2 by switching H and T. Other edits were changing or adding activities. S was the unique activity in Scenario 1. C and D are the unique activities in Scenario 2.

RESULTS

A total of 19 videos were analyzed, 12 were of the 15-month-old and seven were of the 1-month-old. Median time of each video was 10 minutes and 31 seconds (IQR 2 minutes, 4 seconds). There were between three and six EMS providers participating in each simulation with a median of four providers.

Activities

A total of 17 distinct activities were captured (Table 1). The number of activities completed during each simulation varied between 16 and 21 for the 15-month scenario and 13 and 24 for the 1-month scenario with the median number of activities equaling

Activity name	Activity description	15-month-old scenario (n=12)			1-month-old scenario (n=7)		
		Number of times observed	Number of videos in which activity observed	Mean duration (min, max)	Number of times observed	Number of videos in which activity observed	Mean duration (min, max)
Basic Airway	Airway assessment, chin lift, opening of airway	4	4	69 (6, 194)	2	2	117 (47, 187)
BGL	Obtain blood glucose level using glucometer	12	12	82 (12, 307))	9	7	43 (3, 288)
BMV	Bag-mask ventilation: Application of mask on face, seal around face, ventilation using anesthesia or self-inflating bag	11	11	58 (8, 136)	7	7	36 (17, 63)
BP measure	Application of BP cuff, manual or machine automated cuff inflation	17	10	48 (4, 122)	10	7	61 (7, 455)
ECG (electrocardio-gram)	Application of 3 electrodes to correct locations, connection to monitor	11	11	9 (3, 26)	5	5	39 (7, 142)
EtCO2	Application of $ETCO_2$ monitor to patient, connection to monitor	8	8	55 (23, 160)	1	1	6 (6,6)
IV_IO	Intravenous or intraosseous line placement	16	12	176 (25,440)	7	7	149 (68, 246)
IV fluid	Intravenous or intraosseous fluid administration	14	11	190 (41,588)	11	7	218 (68, 489)
Medication administration	Determining medication dose, drawing up medication in syringe, administration through IN, IO, or IV route	14	12	150 (41, 245)	9	7	106 (40, 269)
Oxygen delivery	Delivery of oxygen through face mask, nasal canula, bag mask ventilation	1	1	69 (69, 69)	0	0	
Oxygen measure	Application of continuous pulse oximetry, attachment of lead to monitor	11	11	73 (7, 161)	7	7	47 (2, 100)
Pulse check	Manual check of pulse in femoral, brachial, or carotid location	26	12	24 (3, 87)	16	7	22 (4, 53)
Pulse Oximetry	Application of pulse oximetry probe and connection to monitor	11	11	22 (9, 72)	7	7	17 (8,26)
Radio report	Delivery of summary of case and clinical care in prearrival notification to hospital	12	12	74 (55, 138)	7	7	56 (39, 83)
Respiration check	Listening to breath sounds during spontaneous respirations or ventilated breaths	33	12	6 (4, 10)	17	7	24 (7, 45)
Response check	Mental status assessment	7	5	39 (7, 429)	5	4	7 (3, 14)
Weight estimate	Use of length-based tape or asking for weight from caregiver	13	12	23 (5, 52)	7	7	13 (9, 19)

Table 1. Activities included in videos (All durations are in seconds)

18.5 for the 15-month-old and 18 for 1-month-old. Overall, not all activities were performed in every simulation, and some activities were performed multiple times in a single simulation. Median durations of the simulations were 653 and 593 seconds for 15 months and 1-month scenarios, respectively (Table 2). Median idle times (i.e., no team member was performing any documented tasks) in a simulation was 18 and 10 seconds for 15-month and 1-month scenarios respectively. On average, 4% and 5% of idle time occurred for the 15-month and 1-month scenarios respectively.

	15-month scenario (n=12)	1-month scenario (n=7)
Mean number of activities, (min, max)	18.4 (16, 21)	18.1 (13, 24)
Median number of activities	18.5	18
Mean duration (min, max), seconds	653 (524, 849)	593 (438, 831)
Median duration, seconds	646	606
Mean idle time (min, max), seconds	24 (0, 63)	25 (0, 58)
Median idle time, seconds	18	10
Mean idle time ratio	4%	5%
Mean multitask ratio (min, max)	102% (52, 202)	94% (57, 155)
Median multitask ratio	96%	92%
min=minimum, max=maximum		

Table 2. Descriptive Statistics for Videos (n=19)

Roles

The number of team member involved in each video varied between three and six. Activities were frequently accomplished by one or two people, but sometimes these activities could take three people (Table 3).

	Number of times in 15 month scenarios	Number of times in 1 month scenarios
Activities that involved 3 personnel		
Basic airway	0	1
BMV	3	1
IV-IO	5	1
Medication administration	6	1
Oxygen measure	2	0
Pulse check	5	0
Respiration check	1	1
Activities that involved 2 personnel		
Basic airway	2	1
BP Pressure	3	0
BVM	4	1
$ETCO_2$	5	0
IV Fluid	5	4
IV_IO	4	4
Medication administration	4	4
Oxygen measure	4	1
Pulse check	2	2
Pulse oximetry	1	0
Respiration check	2	1
Response check	1	2
Weight estimate	5	1

Table 3. Activities involved multiple people

Concurrence and Sequence

In two of the 15-month simulations, six activities were conducted concurrently at least once. In five videos (four in 15-month and one in 1-month simulations), at most, three activities were conducted concurrently.

Mean multitask ratio was 102% and 94% for 15-month and 1-month scenarios respectively. Only 12-55% (mean 36%) of the time did EMS personnel conduct one or no activity in a simulation. The minimum pairwise Levenshtein distance for both scenarios is 11 which means 11 activities would be edited to transform one simulation to another. The median pairwise Levenshtein distance for both scenarios is 15. The maximum pairwise distance was 18 for 15-month scenario and 19 for 1-month scenario (See Appendix).

DISCUSSION

Workflow analysis is critical to understanding complex systems such as the healthcare environment and is an important component to consider when implementing process improvement. To date, there has been limited workflow research in prehospital environments, particularly in the care of pediatric emergencies. In this study, we characterized workflow among teams of EMS practitioners, using a systematic approach in the evaluation of a series of simulations in which the patient's condition and environment were controlled. More importantly, we presented a method to study workflow for EMS work. We found a significant degree of variability; particularly in the number and type of activities performed in each scenario, the sequence of these activities, as well as the number of team members involved. Not surprisingly, we also found that EMS teams multitask continuously across the entirety of an out-of-hospital encounter.

What is notable about the degree of variability seen in the EMS team workflow between scenarios is the fact that the physical environment, equipment, and clinical features of the scenario were controlled suggesting that the variability seen is due to EMS provider teamwork and communication alone. Some variability may be due to the experience of the EMS practitioner, or their familiarity with other team members. Prior studies examining errors in out-of-hospital care strongly advocate for interventions to reduce known variabilities that can negatively affect safety and patient outcome issues (Herzberg 2019, Jones 2018, Meckler 2018, Ramadanov 2019). As an example, efforts to reduce variability in care such as "pit crew resuscitation" demonstrate improved outcomes for patients (Hopkins 2016).

Our study is the first use of Levenshtein distance to examine EMS workflow, and one of few studies that has used it in any healthcare settings (Ozkaynak 2013). It is potentially clinically relevant and shows a common degree of sequence variability seen in emergency care. This approach allows evaluation of the effects of various interventions (e.g., training, technology, etc.) on sequence variability by allowing pre and post comparisons without a need for a control group. Although safety and patient outcomes were beyond the scope of our study, our methodology can be used to measure the extent of variability in EMS workflow and provide a standardized metric that can be used as an outcome in intervention studies designed to streamline workflow and standardize care.

Team multitasking is assumed in prehospital care (Norri-Sederholm 2014); however, team multitasking can potentially lead to human error and patient safety issues because of confusing and coordination failures (Chisholm 2000). Our methods can be utilized in future studies to answer questions regarding the optimum number of team members in EMS care and best task sharing policies. Quantifying workflow and multitasking can inform the design, implementation, and evaluation of communication or other team-based interventions that improve team performance and the outcomes of EMS work.

Our finding of the degree of multitasking in the setting of hands-on patient care demonstrates that EMS practitioners may not have the capability to use and interact with handheld computing devices such as those used to collect and document patient data and keep track of team activities. Prior studies examining this issue have made the same conclusion and suggest that degree of variability and multitasking in EMS teams necessitates novel interventions to support EMS providers (Chisholm 2000). For example, hands-free, semi-automated wearable technology such as smart glasses can be adopted to better support EMS workflow (Zhang 2021a, 2021b, 2022). Other studies demonstrate that interventions to improve teamwork11 or integrate health information technology (HIT) (Zhang 2020) can improve EMS care.

During the brief moments of idle time, the subjects were not providing care to the patient. The nature of the reason behind the idle time was not directly analyzed, however, pauses in treatment is common to allow devices to calibrate (e. g., ECG recording) or to observe response to treatment (e. g., anti-seizure or glucose medication). The study investigator measuring time and duration of activities did include the time determining a dose of medication, drawing up the appropriate volume, and administration of the medication all as an activity.

Our previous study which focused on inefficiencies and patient safety issues using the same dataset highlighted that EMS teams failed to perform certain tasks due to "lack of closed-loop, directed communication", "inappropriate or lack of task sharing and coordination", and "lack of situational awareness." This is similar to other studies examining EMS teams in simulation where a number of tasks are not completed (Lammers 2009). In fact, even when using a checklist, EMS teams can fail to do up to 50% of tasks (Alphonso 2017). Variability in workflow and team multitasking can lead to these issues if EMS teams are insufficiently supported.

Computerized decision support technologies have been utilized in other healthcare settings to prompt clinicians to perform certain interventions or collect information (Jaspers 2011), and HIT interventions have been shown to improve decision making by EMS personnel. However, smooth integration of HIT to workflow has been identified as a challenge8 and requires methods to evaluate workflow to facilitate integration of interventions. We found very little idle time in each scenario suggesting that HIT must be integrated into existing activities but not increase the number of activities that must be completed or performed by the EMS practitioner, yet be sufficiently flexible to accommodate the variability in workflow.

Studies demonstrate that interventions informed by workflow analysis during design, implementation and evaluation phases can possibly lead to better health outcomes (Ozkaynak 2016, Zhang 2020). This study presents a systematic approach to examine EMS workflow so that intervention designers, implementers, and evaluators can use it to inform their work.

Future research should include the design of participatory or non-participatory field studies to confirm these findings. Qualitative studies may identify the factors that influence the degree and extent of multitasking and its consequences. These types of studies can also evaluate factors associated with the variability in type of activities conducted including their sequence, which team members are involved, and how this affects the quality and safety of care. Our study focused on activities, roles, and sequence. However, other work elements such as data flow could be integrated as well.

LIMITATIONS

The limitations of this study included the inherent difficulty in observing teamwork through video monitoring and the inability to fully understand the team member's motivation. Although all videos were assessed for audiovisual clarity, some team tasks may have occurred outside the visual field of the cameras and audio recordings may not have captured all verbal communication clearly. In addition, body language or non-verbal communication is more difficult to detect. Team member motivation is difficult to determine without audible cues. One cannot expect simulations to replicate how one would respond in the field, since mistakes made on a mannequin do not have the same consequences of those made during actual patient care. Teams and individuals performed tasks on occasion without verbalizing their plan of care.

Despite the great potential of simulations, de-contextualizing collaborative work by performing it in a laboratory setting, may affect not only the primary work activities, but also the background work that enable these activities. Within healthcare, the importance of, for instance, articulation work (Corbin 1993) (i.e., activities that are not a part of activities toward primary goal but makes primary goal activities possible) has been found to be critical to take into account in coordination of medical settings (Abraham 2013). This often subtle and highly contingent background work may be difficult to recreate in a simulated setting, which introduces the uncertainty that the problems observed may in fact be caused by the absence of normal routine.

This is a secondary analysis from a previous study. High variability in crew numbers and levels of licensure can be considered as a limitation, however team composition in simulations mirrored the exact composition of teams in the field as the participants were on shift at the time of simulation practice. Although some simulations did not require treatment of seizure activity, all tasks reviewed included essential aspects of prehospital care regardless of whether the patient had a seizure in the first 5 minutes. In addition, we intentionally chose only a fraction of the available videos for our analysis, but a larger sample size may have allowed us to find additional nuances in workflow not noted in the selection of videos that we did review. We did employ a single video reviewer which may skew our findings; however, our reviewer did undergo training and has a background in prehospital care.

The performance of EMS personnel is affected by many factors; however, the scope of this study was limited to workflow issues.

CONCLUSIONS

We were able to identify many of the tasks used by EMS personnel and the duration of time to complete such tasks. This method of identifying and quantifying EMS tasks may be useful in workforce allocation, identifying strengths and weaknesses of team members, or to evaluate a team member's readiness for the field. Additionally, our findings can inform the development of interventions, specifically the design, implementation, and evaluation of HIT and other teamwork interventions designed to improve the outcomes of EMS care.

REFERENCES

Abraham, J., & Reddy, M. C. (2013). Re-coordinating activities: an investigation of articulation work in patient transfers. In Proceedings of the 2013 conference on Computer supported cooperative work (pp. 67–78).

Alphonso, A., Auerbach, M., Bechtel, K., Bilodeau, K., Gawel, M., Koziel, J., ... & Aghababian, R. V. (2017). Development of a Child Abuse Checklist to Evaluate Prehospital Provider Performance. Prehosp Emerg Care, 21(2), 222-232.

Chisholm, C. D., Collison, E. K., Nelson, D. R., & Cordell, W. H. (2000). Emergency department workplace interruptions: are emergency physicians "interrupt-driven" and "multitasking"? Acad Emerg Med, 7(11), 1239-1243.

Corbin, J. M., & Strauss, A. L. (1993). The Articulation of Work Through Interaction. The Sociological Quarterly, 34(1), 71-83.

Hayden, E. M., Wong, A. H., Ackerman, J., Sande, M. K., Lei, C., Kobayashi, L., ... & Spiro, D. M. (2018). Human Factors and Simulation in Emergency Medicine. Acad Emerg Med, 25(2), 221-229.

Herzberg, S., Hansen, M., Schoonover, A., Skarica, B., McNulty, J., Harrod, T., ... & Iwashyna, T. J. (2019). Association between measured teamwork and medical errors: an observational study of prehospital care in the USA. BMJ Open, 9(10), e025314.

Jaspers, M. W., Smeulers, M., Vermeulen, H., & Peute, L. W. (2011). Effects of clinical decision-support systems on practitioner performance and patient outcomes: a synthesis of high-quality systematic review findings. J Am Med Inform Assoc, 18(3), 327-334.

Jones, D., Hansen, M., Van Otterloo, J., Dickinson, C., & Guise, J. M. (2018). Emergency Medical Services Provider Pediatric Adverse Event Rate Varies by Call Origin. Pediatr Emerg Care, 34(12), 862-865.

Kaufmann, J., & Laschat, M. (2020). Challenges of Being Prepared for Pediatric Emergencies. Prehosp Emerg Care, 24(2), 303-304.

Kothari, K., Zuger, C., Desai, N., Leonard, J., Alletag, M., Balakas, A., ... & Bokovoy, J. (2020). Effect of Repetitive Simulation Training on Emergency Medical Services Team Performance in Simulated Pediatric Medical Emergencies. AEM Educ Train, 5(3), e10537-e.

Lammers, R. L., Byrwa, M. J., Fales, W. D., & Hale, R. A. (2009). Simulation-based assessment of paramedic pediatric resuscitation skills. Prehosp Emerg Care, 13(3), 345-356.

Meckler, G., Hansen, M., Lambert, W., O'Brien, K., Dickinson, C., Dickinson, K., ... & Guise, J. M. (2018). Out-of-Hospital Pediatric Patient Safety Events: Results of the CSI Chart Review. Prehosp Emerg Care, 22(3), 290-299.

Norri-Sederholm, T., Kuusisto, R., Kurola, J., Saranto, K., & Paakkonen, H. (2014). A Paramedic Field Supervisor's Situational Awareness in Prehospital Emergency Care. Prehospital and Disaster Medicine, 29(2), 151-159.

Ozkaynak, M. & Brennan, P. F. (2012). Characterizing patient care in hospital emergency departments. Health Systems, 1(2), 104-117.

Ozkaynak, M., & Brennan, P. F. (2013). Revisiting sociotechnical systems in a case of unreported use of health information exchange system in three hospital emergency departments. J Eval Clin Pract, 19(2), 370-373.

Ozkaynak, M., Reeder, B., & Drake, C. (2019). Characterizing Workflow to Inform Clinical Decision Support Systems in Nursing Homes. The Gerontologist, 59(6), 1024-1033.

Ozkaynak, M., Reeder, B., & Park, S. Y. (2020). Design for improved workflow. In F. Sasangohar & A. Sethumadhavan (Eds.), Design for Healthcare. Elsevier.

Ozkaynak, M., & Wu, D. T. Y. (2018). Examining workflow in a pediatric emergency department to develop a clinical decision support for an antimicrobial stewardship program. Applied Clinical Informatics, 9(2), 248-260.

Ozkaynak, M., Dziadkowiec, O., Mistry, R., Callahan, T., He, Z., Deakyne, S., ... & Gurses, A. P. (2015). Characterizing workflow for pediatric asthma patients in emergency departments using electronic health records. J Biomed Inform, 57, 386-398.

Ozkaynak, M., Ponnala, S., & Werner, N. E. (2019). Patient-Oriented Workflow Approach. In K. Zheng, J. Westbrook, T. G. Kannampallil, & V. L. Patel (Eds.), Cognitive Informatics Reengineering Clinical Workflow for Safer and More Efficient Care. Springer.

Pentland, B. T. (2003). Conceptualizing and Measuring Variety in the Execution of Organizational Work Processes. Management Science, 49(7), 857-870.

Ramadanov, N., Klein, R., Schumann, U., Aguilar, A. D. V., & Behringer, W. (2019). Factors influencing medication errors in prehospital care: A retrospective observational study. Medicine (Baltimore), 98(49), e18200.

Zhang, Z., Brazil, J., Ozkaynak, M., & Desanto, K. (2020). Evaluative Research of Technologies for Prehospital Communication and Coordination: a Systematic Review. Journal of Medical Systems, 44(5), 100.

Zhang, Z., Sarcevic, A., Joy, K., Ozkaynak, M., & Adelgais, K. (Eds.). (2021a). User Needs and Challenges in Information Sharing between Pre-Hospital and Hospital Emergency Care Providers. In American Medical Informatics Association Annual Symposium; San Diego, CA.

Zhang, Z., Joy, K., Upadhyayula, P., Ozkaynak, M., Harris, R., & Adelgais, K. (2021b). Data Work and Decision Making in Emergency Medical Services: A Distributed Cognition Perspective. Proc ACM Hum-Comput Interact, 5(CSCW2), Article 356.

APPENDIX

Pairwise distances of the workflows for 15-month scenarios

	imklahikbngofekkjdcrf	thkcimfgodikbejik	bimhktkfgcdjefogenk	itbikhmgfckoeidfjikb	tkkdimefkgmhonckj	ilbktcdfoigmanеblj	ikmidoghnbctkfaebkji	ihboktfsegmfjibe	ibhdmtfcigoaejbk	hlkbnmitodigfkcbekjk	mbtdoihkifgcknjlbig	imhkntokgdcflekljk
imklahikbngofekkjdcrf												
thkcimfgodikbejik	16											
bimhktkfgcdjefogenk	18	14										
itbikhmgfckoeidfjikb	17	13	15									
tkkdimefkgmhonckj	17	12	16	15								
ilbktcdfoigmaneblj	18	15	15	15	14							
ikmidoghnbctkfaebkji	16	15	17	16	16	16						
ihboktfsegmfjibe	16	14	15	12	15	11	16					
ibhdmtfcigoaejbk	16	13	13	13	13	11	14	11				
hlkbnmitodigfkcbekjk	17	11	17	17	15	15	15	15	14			
mbtdoihkifgcknjlbig	16	15	15	16	16	15	16	15	13	17		
imhkntokgdcflekljk	15	13	12	15	15	13	15	14	13	13	16	

Pairwise distances of the workflows for 1-month scenarios

	khidkbtfklacimeogiggibej	ihfdtbogeikbmcanikj	bmithofgecjkbeo	lihibftekcimoigekj	ktckideflmoghkjboekk	imktdhcobfegj	khbtmdliceklfiokgj
khidkbtfklacimeogiggibej							
ihfdtbogeikbmcanikj	18						
bmithofgecjkbeo	19	15					
lihibftekcimoigekj	14	13	14				
ktckideflmoghkjboekk	18	18	16	16			
imktdhcobfegj	17	15	11	12	15		
khbtmdliceklfiokgj	16	15	15	15	16	12	

Legend: These two tables show the pairwise comparison of the workflow extracted from simulations (n=12 for 15-month scenario and n=7 for 1-month scenario) In each table the first column and first row lists the simulations (e.g., first element of first column and first element of first row are same and show the first scenario etc.). The numbers represent the dissimilarity between the simulations at the corresponding row and the corresponding column. For example, in the second table, the dissimilarity between the simulation listed in the 4th column and the 7th row is 11. The smaller the number shows more similarity between the pair. For example, the dissimilarity between the simulation listed in the same column (4th) and the 8th row is 15. This means that the workflow on the 8th row is more different (15>11) to the workflow on 4th column.

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