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Clinical paper

Impact of flow disruptions in the delivery room

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Abstract

Aim: Flow disruptions (FDs) are deviations from the progression of care that compromise safety and efficiency of a specific process. The study aim was to identify the impact of FDs during neonatal resuscitation and determine their association with key process and outcome measures.

Methods: Prospective observational study of video recorded delivery room resuscitations of neonates <32 weeks gestational age. FDs were classified using an adaptation of Wiegmann's FD tool. The primary outcome was target oxygenation saturation achievement at 5 min. Secondary outcomes included achieving target saturation at 10 min, time to positive pressure ventilation for initially apnoeic/bradycardic neonates, time to electrocardiogram signal, time to pulse oximetry signal, and time to stable airway. Multivariable logistic regression assessed association between FDs and achieving target saturations adjusting for gestational age and leader. Associations between FDs and time to event outcomes were assessed using Cox proportional hazards models.

Results: Between 10/2017–7/2018, 32 videos were included. A mean of 52.6 FDs (standard deviation 17.9) occurred per resuscitation. Extraneous FDs were the most common FDs. FDs were associated with an adjusted odds ratio of 0.92 (95% confidence interval [CI] 0.80–1.05) of achieving target saturation at 5 min and 0.94 (95% CI 0.84–1.05) at 10 min. There was no significant evidence to show FDs were associated with time to event outcomes.

Conclusions: FDs occurred frequently during neonatal resuscitation. Measuring FDs is a feasible method to assess the impact of human factors in the delivery room and identify modifiable factors and practices to improve patient care.

Keywords: Delivery room, Neonatal resuscitation, Human factors, Flow disruptions

Introduction

The majority of preterm neonates require stabilization or resuscitation after birth in the delivery room (DR).[1] The Neonatal Resuscitation Program® (NRP®) provides an effective and specific algorithm for the medical steps of neonatal resuscitation, but performing quality resuscitation goes beyond algorithm adherence. The complex DR system requires coordination of multiple factors including provider training, teamwork, communication, equipment, and an appropriate space. Given the interplay of patient, provider, and environmental factors, a critical knowledge gap is how to optimize this setting to maximize providers' ability to perform effective NRP®.

Human Factors, the scientific discipline concerned with understanding interactions among humans and other elements of a system,[2] offers a unique perspective for evaluating the DR. Most DR human factors studies focused on deviations from NRP® or standardizing communication.[3–7] Although errors during DR resuscitation

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https://doi.org/10.1016/j.resuscitation.2020.02.037
Received 4 November 2019; Received in revised form 20 February 2020; Accepted 26 February 2020
Available online xxx

are common,[3–5] the systematic conditions that predispose to these errors have not been identified. Flow Disruptions (FDs) are defined as deviations from the progression of care that compromise safety and efficiency of a specific process derived from direct observations of clinical work.[8] A FDs tool was first developed for the cardiovascular operating room as a method for objectively measuring and classifying the impact of human factors in a high acuity medical setting.[8] This tool has since been modified and studied in numerous medical fields including cardiovascular surgery, general surgery, robotic surgery, cardiac anaesthesia, and trauma resuscitation in the emergency room.[9–15] FDs contribute to errors, accidents, and in some cases, adverse outcomes.[8] Since they demonstrate systemic failures to support human performance, FDs can be used to identify, evaluate, and rectify hidden mismatches between people and systems. Subsequent classification and rectification of these breakdowns have led to improvements in the operating room and trauma bay settings.[8,10–13,16]

Similar to the operating room and trauma bay, the DR is a high acuity setting that requires coordination of providers, environment, and equipment. The objectives of this study were two-fold: first, to identify and classify FDs during neonatal resuscitation, and second, to determine the association between number and type of FDs and key process and outcome measures of neonatal resuscitation.

Methods

Setting and design

This was a pilot single-centre prospective observational study in a level III academic delivery hospital. Resuscitations for all high-risk deliveries are performed in a separate infant resuscitation room adjoining the obstetrical operating suite, and the resuscitation team completes a pre-resuscitation huddle with checklist before each delivery at this site. Video recording is routine practice at this site for all high-risk deliveries for quality improvement purposes. The video recordings include audio and three visual outputs: a close view of the patient, a wide-angle view of the providers, and simultaneous video feed output from the vital sign monitor. This study was deemed quality improvement exempt from institutional review board oversight.

Procedure

Video recorded DR resuscitations of neonates less than 32 weeks gestational age were analysed for FDs by a single observer who received FD training from a human factors expert. Video analysis started at time of birth and continued until establishment of a stable airway (defined below) or 10 min, whichever was greater. If a stable airway was not established, videos were analysed for 30 min. Inclusion criteria: Resuscitations of singleton neonates less than 32 weeks gestational age who required respiratory support during resuscitation. Exclusion criteria: Resuscitations of neonates $\geq$32 weeks gestational age, congenital anomalies, multiple gestation, no need for respiratory support, a video recording that did not capture time of birth or did not last 10 min, or a video recording with a blocked view.

FDs were classified according to a modified version of Wiegmann's FD tool[8,10] (Table 1). The FD tool was modified with input of both a human factors expert and a neonatal resuscitation expert. The time, category, impact, and a brief description were documented for each FD. Impact was classified as low (minimal disruption to the progression of the resuscitation), medium (some disruption to the progression of the resuscitation), or high (total cessation of the progression of the resuscitation for any duration), consistent with a previous FD study.[10] Prior to study initiation, five video recordings were analysed for FDs and discussed with both a resuscitation expert and a human factors expert to develop consistent FD documentation. During the study, all unclear FDs were discussed with study team members with consensus ruling. Resuscitation characteristics collected included patient birth gestational age and weight, team leader training level, daytime resuscitation (defined as 8:00AM-5:30PM), weekday (Monday through Friday) versus weekend (Saturday and Sunday) resuscitation, levels of support required, and adequate team notification (defined as $\geq$5 min notification prior to time of birth).

The primary outcome was achievement of target oxygen saturation at 5 min defined as 80%–95% SpO_2 or $\geq$80% SpO_2 if the FiO_2 was 21%. The 5 min oxygen saturation was the median value of saturations recorded every 10 s during the 5th minute of life. Secondary outcomes were achievement of target oxygen saturation at 10 min (median oxygen saturation of 85–95% or $\geq$85% if the FiO_2 was 21%), time to initiation of positive pressure ventilation (PPV) defined as time from birth to time of initiation of PPV for patients who were initially apnoeic or bradycardic (heart rate [HR] < 100 beats per min [bpm]), time to ascertain reliable electrocardiogram (ECG) signal defined as time of placement of neonate on resuscitation bed to time of clearly visible QRS complexes for $\geq$2 s, time to reliable pulse oximetry (PO) signal defined as time of placement of neonate on resuscitation bed to time of clearly visible plethysmographic waveforms for $\geq$2 s, and time to stable airway defined as time of placement of neonate on resuscitation bed to time of secured nasal cannula, secured nasal continuous positive airway pressure (CPAP) prongs, or taped endotracheal tube (ETT) with a HR > 100 bpm.

Statistical analysis

All analyses were conducted using Stata 16.0 (Stata Corp, College Station, TX). Descriptive statistics examined frequency, classification, and impact of FDs per resuscitation. We assessed the association between each resuscitation characteristic and the number of FDs before 5 min using Poisson regression with FD count as the dependent variable. We used multivariable logistic regression models to examine the impact of number of FDs and each individual category of FDs on achieving target oxygen saturation at 5 and 10 min, censoring FD based on time of the event. We performed a post hoc analysis exploring the impact of supervisory (training and technical skill) and non-supervisory FDs (all categories of FDs except training and technical skill) on achievement of target oxygen saturation at 5 and 10 min. Associations between FDs and time to event outcomes (time to PPV, ECG, PO, and stable airway) were assessed using Cox proportional hazards models with cumulative number of FDs as a time-varying covariate. Cumulative FD count started at placement of patient on the resuscitation bed for time to ECG, PO, and stable airway, and the number of FDs from birth to placement on resuscitation bed was included as separate variable in the models. All patients were included in time to event analyses for ECG, PO, and stable airway. For time to PPV, the cumulative number of FDs was measured from time of birth. Only patients who required PPV for initial apnoea or bradycardia were included in time to event analysis for PPV. We used the Schoenfeld residuals to examine proportionality. A p-value of $<$0.05 was considered statistically significant, and a p-value of $<$0.2 was used as the threshold to consider resuscitation

Please cite this article in press as: H.M. Herrick, et al., Impact of flow disruptions in the delivery room, Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.02.037

Table 1 – Neonatal delivery room flow disruptions.[a]

Flow disruption category	Definition	Example
Communication	Disruptions that involve the verbal transitions of information between at least two team members, including lack of acknowledgement or response to communication.	Nurse asks resident to speak up as too many people are talking.
Coordination	Disruptions that involve the interaction with some piece of equipment as well as at least one other team member or disruptions where multiple team members are engaged in tasks that hinder one another.	Airway provider has to ask for mask multiple times and ultimately has to grab mask herself because RT has not yet adjusted mask properly/mask is not ready.
Extraneous interruptions	Disruption occurring during the resuscitation that did not directly pertain to the treatment of the patient and resulted in disruptions of resuscitation flow.	Obstetrician comes in to ask team how baby is doing and when parents can come in to see baby.
Equipment-technology-layout	Malfunctions of technologic equipment or delays secondary to layout or equipment design or performance resulting in resuscitation delays.	1) Intubation delayed because light on laryngoscope is not working. 2) Cannot adequately see respiratory effort through neo-wrap. 3) Nurse has to retrieve airway box which is below resuscitation bed requiring resident to step away from the bedside.
Resource-based issues	Failure to progress to the next stage of the resuscitation because of a lack of resources available at the resuscitation table.	Intubation delayed because appropriately sized endotracheal tube is not immediately available.
Training[b]	Training or supervision that hinders the natural progression of the resuscitation.	Intubation is delayed because attending is teaching resident how to hold laryngoscope.
Technical skills[b]	Skill-based or decision (thinking) error, including poorly executed tasks, omitted steps, or misinterpretation of relevant information.	Medical student did not know how to properly connect the monitor.

[a] Adapted from Wiegmann's flow disruption tool.[8,10]
[b] Training and technical skills combined represent supervisory flow disruptions.

characteristic inclusion in the multivariable logistic regression models and Cox proportional hazards models. The study was designed to continue until saturation of types of FDs was achieved, with a minimum sample of 30 resuscitations.

Results

A total of 32 video recorded neonatal resuscitations were analysed between October 2017 and June 2018 (Supplemental Fig. 1), at which point saturation of types of FDs was achieved. Patient, provider, and resuscitation characteristics are presented in Table 2. The median gestation age was 28.1 weeks and the mean birth weight was 996 g. All neonates received either CPAP or PPV, and the majority of neonates were trialed on CPAP during the resuscitation. Intubation was attempted during nine resuscitations, and seven neonates were successfully intubated. No neonates required chest compressions or adrenaline (epinephrine), and all neonates survived. The median length of analysed resuscitation was 11 min and 35 s (interquartile range [IQR] 10 min 50 s–16 min 11 s).

A mean of 52.6 FDs (standard deviation [SD] 17.9) occurred per resuscitation with a median of 3.7 FD per minute (IQR 3.4–4.3). Extraneous FDs were the most common type of FD with a mean of 19.5 (SD 7.8) per resuscitation followed by equipment-technology-layout FDs and communication FDs (Table 3). Frequent extraneous FDs included phone calls, pages, obstetrical team interruptions, and other personnel entering and exiting the DR. Low impact FDs occurred most frequently (mean 44.8, SD 13.8) followed by medium impact and then high impact. Fig. 1 shows the proportion of FD categories by impact. Supplemental Fig. 2 demonstrate the distribution of FDs by minute of resuscitation. None of the resuscitation characteristics were statistically significantly associated with the number of FDs (data not shown).

Table 2 – Patient and resuscitation characteristics.

Characteristics	N = 32
Gestational age, weeks; median [IQR]	28.1 [25.2–30.7]
Birth weight, grams; mean (SD)	995.6 (413.4)
Weekday resuscitation[a]; n (%)	26 (81.3%)
Daytime resuscitation[b]; n (%)	21 (65.6%)
Team notification ≥ 5 min prior to birth; n (%)	31 (96.9%)
Role of initial team leader; n (%)	
Fellow	19 (59.4%)
Attending	12 (37.5%)
NP/PA	1 (3.1%)
Change in leader during resuscitation; n (%)	7 (21.9%)
Type of support during resuscitation[c]; n (%)	
Room air	5 (15.6%)
CPAP	29 (90.6%)
PPV	28 (87.5%)
Intubation attempt	9 (28.1%)
Successful intubation	7 (21.9%)
Chest compression	0
Adrenaline (epinephrine)	0

IQR = interquartile range, SD = standard deviation NP/PA = nurse practitioner/physician's assistant, CPAP = continuous positive airway pressure, PPV = positive pressure ventilation.
[a] Defined as Monday through Friday.
[b] Defined as 8:00 AM through 5:30 PM.
[c] Support at any time during resuscitation, can select multiple.

Table 3 – Frequency, classification, and impact of flow disruptions.

	Count per resuscitation
Total flow disruptions; mean (SD)	52.6 (17.9)
Category of flow disruptions	
Extraneous; mean (SD)	19.5 (7.8)
Equipment, technology, & layout; mean (SD)	13.9 (6.3)
Communication; median [IQR]	9.5 [5–14]
Coordination; mean (SD)	4.1 (2.3)
Resource; mean (SD)	2.3 (1.9)
Technical skill; median [IQR]	1 [0.5–2]
Training; median [IQR]	0 [0–1]
Impact of flow disruptions	
High impact; median [IQR]	1 [0–3.5]
Medium impact; mean (SD)	4 [2–6]
Low impact; mean (SD)	44.8 (13.8)

FD = flow disruption, SD = standard deviation, IQR = interquartile range.

Table 4 – Patient and process outcomes.

	N = 32
Target oxygen saturation at 5 min; n (%)	13 (40.6%)
Target oxygen saturation at 10 min; n (%)	24 (75%)
Time to PPV, seconds[a]; median [IQR]	49 [35–67] N = 22
Time to ECG signal, seconds[b]; median [IQR]	86 [53–223] N = 30
Time to PO signal, seconds[c]; median [IQR]	78 [62–121]
Time to stable airway, seconds[d]; mean (SD)	653 [446–983] N = 31

PPV = positive pressure ventilation, IQR = interquartile range, ECG = electrocardiogram, PO = pulse oximetry, SD = standard deviation.
[a] Defined as time of birth to initiation of PPV if initially apneic or Heart Rate (HR) < 100 beats per minute (bpm).
[b] Defined as time of placement on resuscitation bed to time of clearly visible QRS complexes with reading for ≥2 s.
[c] Defined as time of placement on resuscitation bed to time of clearly visible plethysmographic waveforms with reading for ≥2 s.
[d] Defined as time of placement of neonate on resuscitation bed to time of secured nasal cannula, secured nasal continuous positive airway pressure (CPAP), or taped endotracheal tube (ETT) with a HR > 100 bpm.

Patient and process outcomes are presented in Table 4. Target oxygen saturation at 5 and 10 min were achieved in 41% and 75% of the resuscitations respectively. Only 22 of the 32 neonates required PPV for initial apnoea or bradycardia. Reliable ECG and PO signals were achieved in 30 and 32 resuscitations respectively. All providers established a stable airway during the video assessment, with the exception of one resuscitation in which the patient remained on bag-mask CPAP due to equipment malfunction.

In multivariable logistic regression accounting for patient gestation and team leader training level, increasing FDs was associated with lower odds of achieving target oxygen saturation at 5 min (adjusted Odds Ratio [aOR] 0.92, 95 % confidence interval [CI] 0.80–1.05) and 10 min (aOR 0.94, 95% CI 0.84–1.05), although not significant (Table 5). In post-hoc analysis, non-supervisory FDs were associated with an aOR of 0.90 (95% CI 0.79 –1.03) and 0.93 (95% CI 0.83–1.05) of achieving target oxygen saturations at 5 and 10 min respectively. Supervisory FDs were associated with an aOR of 1.62 (95% CI 0.76–3.46) and 1.10 (95% CI 0.66–1.85) of achieving target oxygen saturations at 5 and 10 min respectively.

In multivariable Cox proportional hazards model accounting for gestational age and team leader training level, FDs were associated

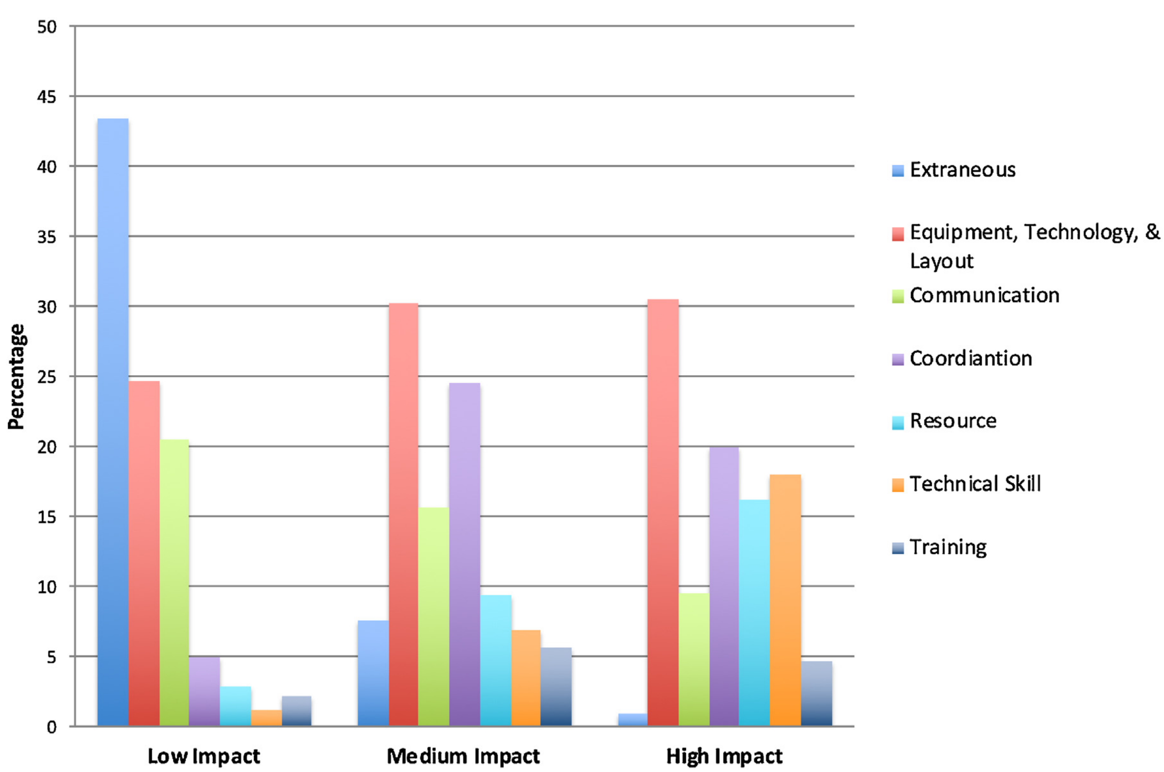

Fig. 1 – Proportion of flow disruption categories by impact.

Please cite this article in press as: H.M. Herrick, et al., Impact of flow disruptions in the delivery room, Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.02.037

Table 5 – aOR[a] of achieving target oxygen saturations.

Target oxygen saturation at 5 min	aOR (95% CI)	P-value
Total flow disruptions	0.92 (0.80−1.05)	0.2
Category of flow disruptions		
Extraneous	0.82 (0.61−1.11)	0.21
Equipment, technology, & layout	0.91 (0.72−1.14)	0.41
Communication	0.98 (0.81−1.19)	0.86
Coordination	0.63 (0.34−1.17)	0.14
Resource	0.94 (0.43−2.04)	0.88
Technical skill	4.82 (0.87−26.5)	0.07
Training	1.24 (0.54−2.83)	0.61

Target oxygen saturation at 10 min	aOR (95% CI)	P-value
Total flow disruptions	0.94 (0.84−1.05)	0.28
Category of flow disruptions		
Extraneous	0.98 (0.82−1.16)	0.79
Equipment, technology, & layout	0.93 (0.76−1.13)	0.45
Communication	0.93 (0.78−1.11)	0.43
Coordination	0.95 (0.59−1.52)	0.83
Resource	0.56 (0.26−1.21)	0.14
Technical skill	0.82 (0.38−1.78)	0.62
Training	2.13 (0.43−10.62)	0.36

aOR = adjusted odds ratio, CI = confidence interval.
[a] Adjusted for patient gestational age and training level of team leader.

with an adjusted hazards ratio (aHR) for time to PPV of 1.12 (95% CI 0.97−1.3), 0.90 (95% CI 0.80−1.02) for time to ECG signal, 1.02 (95% CI 0.90−1.16) for time to PO signal, and 0.97 (95% CI 0.94−1.01) for time to stable airway.

Discussion

To our knowledge, this is the first study to characterize FDs and to assess the impact of FDs in the DR. FDs occurred frequently during neonatal resuscitation, with a mean of 52.6 FD per resuscitation and a median of 3.7 FD per minute. The number of FDs was not significantly associated with the primary outcome of achieving target oxygenation saturation at 5 min or other secondary process and outcome measures.

The rate of FDs reported in this study is higher than those reported in the operating room and trauma bay. The increased rates of FDs seen in our study may be due to the fact we used video review rather than direct in-person observation which allowed repeated in-depth analysis of the videos, minimizing the potential for missed FDs. The rates of FDs documented in studies using video review are higher than studies using direct in-person observation.[8−13,15,17−23] Additionally, while the DR shares some similarities with the operating room and trauma bay, neonatal resuscitation may be intrinsically different from operations and trauma stabilization. Neonatal resuscitation is a brief, high intensity act with an extremely small patient necessitating a constrained working space. FDs reported in operating rooms are primarily from non-emergent cases. In the trauma bay, higher acuity trauma cases were associated with an increased number of FDs.[10,11]

Extraneous FDs, interruptions not pertaining to the actual resuscitation, were the most common FDs followed by equipment-technology-layout FDs. This is consistent with the majority of FD literature, where extraneous FDs or layout FDs occurred most frequently.[9,12,15,18,20,22] Low impact FDs comprised the majority of FDs, but at least one high or medium impact FD occurred in each resuscitation. While the lower rate of high and medium FDs is reassuring, there is growing literature that minor disruptive events may cluster together and predispose to major adverse events.[8,24,25] In one study of 28 video recorded operations, the rate of major FDs increased linearly with increasing rate of minor FDs.[15]

While this pilot study was not powered to detect a significant association between FDs and primary or secondary outcomes, interesting trends and themes emerged. Although not significant, there was a trend toward decreased odds of achieving target oxygen saturations as the number of FDs increased at both 5 and 10 min of life. Further, types of FDs varied by impact. Extraneous interruptions were the most common low impact FD, while equipment-technology-layout FDs and coordination FDs were the most common medium and high impact FDs.

Additionally, the number and impact of types of FDs varied by timing during the resuscitation. FD rates were the highest in the first 3 min of resuscitation. Coordination FDs had the lowest aOR of achieving 5 min target oxygen saturation, while resource FDs had the lowest aOR of achieving 10 min target oxygen saturation. Coordination FDs may have a higher impact during the initial stages of resuscitation when multiple tasks are performed concurrently: placement of neonate on the resuscitation bed, performing thermoregulation manoeuvres, application of ECG and PO leads, assessment of initial HR and breathing, and initiation of respiratory support. Resource FDs seemed to have a larger impact later, when the resuscitation progressed to require equipment not readily available at the bedside. There may be time-sensitive or task-sensitive periods during resuscitation that are more vulnerable to specific types of FDs. The variation in impact by FD type and timing has implications for future intervention design.

Lastly, it appears that not all FDs are harmful, and certain FDs may be necessary. Both training and technical skill FDs had a trend toward increased odds of achieving target 5 min oxygen saturation. Training FDs, defined as training or supervision that hinders the natural progression of the resuscitation, may have improved resuscitation techniques of trainees and increased the likelihood of achieving target saturations. Technical skill FDs are skill-based or decision errors, including poorly executed tasks, omitted steps, or misinterpretation of relevant information. It is possible technical skill FDs were more often recognized when corrected, and thus it was the correction that was protective rather than the FD. The trend towards increased odds of achieving target 5 min oxygenation saturation led to the post hoc analysis of supervisory and non-supervisory FDs. This is consistent with a prior FD study which grouped technical skills and training FDs into supervisory FDs.[8]

Our study has several strengths. The study site has a well-established video recording program for DR resuscitations. Video recording allowed repeated analysis to minimize risk of missed FDs. This also minimized the risk of the Hawthorne effect given video recording is routine practice at the study site, and the study team was not physically present to observe during resuscitations. Additionally, the study was designed and executed with oversight by a DR resuscitation expert with experience studying resuscitation and a human factors expert with experience studying FDs in other high acuity settings.

For this study, we adapted a human factors tool that was originally designed for the cardiovascular operating room and not specifically for neonatal resuscitation. This tool has previously been adapted and used successfully in multiple other high acuity setting including general surgery, trauma resuscitation, and anaesthesia.[9–15] We worked collaboratively with a human factors expert and a neonatal resuscitation expert to refine the tool to be applicable to neonatal resuscitation. While we believe this tool is generalizable to neonatal resuscitation, future directions include qualitatively examining these FDs to determine underlying themes that may be unique to neonatal resuscitation and may contribute to the design of a neonatal resuscitation specific FD tool.

We also acknowledge study limitations. As previously stated, this study was not powered to detect significant associations between FDs and primary and secondary outcomes. A larger study must be conducted to adequately assess these outcomes. A single observer analysed videos for FDs, introducing the possibility of bias. To minimize this risk of bias, the observer conducted five video reviews prior to study initiation, and all unclear FDs were discussed with study team members with consensus ruling during the study period. The study was conducted at a single academic level III delivery hospital and thus the findings from this study may not be applicable to all DRs. Lastly, we acknowledge the potential for selection of more expected deliveries as we only included resuscitations with a clear time of birth. Less expected deliveries may have additional FDs given lack of time for team preparation.

Despite these limitations, this study contributes to using a novel tool to identify both universal and site specific targets for quality improvement. Measuring FDs during neonatal resuscitation has the potential to reveal common and impactful people-system breakdowns. Future multicentre studies must be conducted to discover the degree to which neonatal resuscitation FDs vary across sites.

Conclusions

Measuring FDs in the DR is a feasible way to measure the impact of human factors in the DR. FDs are common occurrences during DR resuscitation. Measuring FDs has the potential to reveal modifiable factors and practices in the DR to streamline neonatal resuscitation performance and ultimately improve patient care.

Conflicts of interest

None.

Funding

This project is supported by the American Academy of Pediatrics 2017 Neonatal Resuscitation Program Young Investigator Award.

H.H. is supported by a National Institutes of Child Health and Human Development (NICHD) Training Grant (T32HD060550-09). S.L. is supported by Agency for Healthcare Research and Quality (AHRQ) (R01HS023538,R01HS023806, R01HD084819) and the Harriet and Ronald Lassin Endowed Chair in Pediatric Neonatology. K.C. is supported by AHRQ (R01HS0246491, R18HS026625) and the Medical University of South Carolina SmartState Endowed Chair in Clinical Practice and Human Factors. E.F. is supported by a NICHD Career Development Award (K23HD084727).

Funding sources had no role in the study design, collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to submit the manuscript for publication.

CRediT authorship contribution statement

Heidi M. Herrick: Conceptualization, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition. **Scott Lorch:** Methodology, Formal analysis, Writing - review & editing. **Jesse Y. Hsu:** Methodology, Formal analysis, Writing - review & editing. **Kenneth Catchpole:** Conceptualization, Writing - review & editing. **Elizabeth E. Foglia:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2020.02.037.

REFERENCES

1. Weiner G, editor. Textbook of neonatal resuscitation (NRP). 7th ed. American Academy of Pediatrics; 2016. https://ebooks.aappublications.org/content/9781610020251/9781610020251.
2. International Ergonomics Association. Definition and domains of ergonomics. (Accessed 23 September 2019, at www.iea.cc).
3. Yamada NK, Yaeger KA, Halamek LP. Analysis and classification of errors made by teams during neonatal resuscitation. Resuscitation 2015;96:109–13.
4. Carbine DN, Finer NN, Knodel E, Rich W. Video recording as a means of evaluating neonatal resuscitation performance. Pediatrics 2004;106:654–8, doi:http://dx.doi.org/10.1542/peds.106.4.654.
5. Thomas EJ, Sexton JB, Lasky RE, Helmreich RL, Crandell DS, Tyson J. Teamwork and quality during neonatal care in the delivery room. J Perinatol 2006;26:163–9, doi:http://dx.doi.org/10.1038/sj.jp.7211451.
6. Yamada NK, Fuerch JH, Halamek LP. Impact of standardized communication techniques on errors during neonatal resuscitation. J Investig Med 2014;62:266–7 doi:10.231/JIM.0000000000000033.
7. Finer NN, Rich W, Halamek LP, Leone TA. The delivery room of the future. Clin Perinatol 2012;39:931–9, doi:http://dx.doi.org/10.1016/j.clp.2012.09.014.
8. Wiegmann DA, ElBardissi AW, Dearani JA, Daly RC, Sundt TM. Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. Surgery 2007;142:658–65, doi:http://dx.doi.org/10.1016/j.surg.2007.07.034.
9. Souders C, Catchpole K, Hannemann A, et al. Flow disruptions in abdominal sacrocolpopexy: does robotic surgery introduce unforeseen challenges for surgeons? Int Urogynecol J Pelvic Floor Dysfunct 2014;25:S160–1.
10. Shouhed D, Blocker R, Gangi A, et al. Flow disruptions during trauma care. World J Surg 2014;38:314–21, doi:http://dx.doi.org/10.1007/s00268-013-2306-0.
11. Catchpole K, Ley E, Wiegmann D, et al. A human factors subsystems approach to trauma care. JAMA Surg 2014;149:962–8, doi:http://dx.doi.org/10.1001/jamasurg.2014.1208.
12. Palmer G, Abernathy JH, Swinton G, et al. Realizing improved patient care through human-centered operating room design: a human factors methodology for observing flow disruptions in the cardiothoracic operating room. Anesthesiology 2013;119:1066–77, doi:http://dx.doi.org/10.1097/ALN.0b013e31829f68cf.
13. Parker SEH, Laviana AA, Wadhera RK, Wiegmann DA, Sundt TM. Development and evaluation of an observational tool for assessing surgical flow disruptions and their impact on surgical performance.

World J Surg 2010;34:353–61, doi:http://dx.doi.org/10.1007/s00268-009-0312-z.
14. Boquet A, Cohen T, Diljohn F, Cabrera J, Reeves S, Shappell S. A theoretical model of flow disruptions for the anesthesia team during cardiovascular surgery. J Patient Saf 2017;00:1–6, doi:http://dx.doi.org/10.1097/PTS.0000000000000406.
15. Joseph A, Khoshkenar A, Taaffe KM, Catchpole K, MacHry H, Bayramzadeh S. Minor flow disruptions, traffic-related factors and their effect on major flow disruptions in the operating room. BMJ Qual Saf 2019;28:276–83, doi:http://dx.doi.org/10.1136/bmjqs-2018-007957.
16. Cohen TN, Wiegmann DA, Reeves ST, Boquet AJ, Shappell SA. Coding human factors observations in surgery. Am J Med Qual 2017;32:556–62, doi:http://dx.doi.org/10.1177/1062860616675230.
17. Weber J, Catchpole K, Becker AJ, Schlenker B, Weigl M. Effects of flow disruptions on mental workload and surgical performance in robotic-assisted surgery. World J Surg 2018;42:3599–607, doi:http://dx.doi.org/10.1007/s00268-018-4689-4.
18. Weigl M, Antoniadis S, Chiapponi C, Bruns C, Sevdalis N. The impact of intra-operative interruptions on surgeons' perceived workload: an observational study in elective general and orthopedic surgery. Surg Endosc 2015;29:145–53, doi:http://dx.doi.org/10.1007/s00464-014-3668-6.
19. Wheelock A, Suliman A, Wharton R, et al. The impact of operating room distractions on stress, workload, and teamwork. Ann Surg 2015;261:1079–84, doi:http://dx.doi.org/10.1097/SLA.0000000000001051.
20. Antoniadis S, Passauer-Baierl S, Baschnegger H, Weigl M. Identification and interference of intraoperative distractions and interruptions in operating rooms. J Surg Res 2014;188:21–9, doi:http://dx.doi.org/10.1016/j.jss.2013.12.002.
21. Savoldelli GL, Thieblemont J, Clergue F, Waeber JL, Forster A, Garnerin P. Incidence and impact of distracting events during induction of general anaesthesia for urgent surgical cases. Eur J Anaesthesiol 2010;27:683–9, doi:http://dx.doi.org/10.1097/EJA.0b013e328333de09.
22. Zheng B, Martinec DV, Cassera MA, Swanström LL. A quantitative study of disruption in the operating room during laparoscopic antireflux surgery. Surg Endosc Other Interv Tech 2008;22:2171–7, doi:http://dx.doi.org/10.1007/s00464-008-0017-7.
23. Healey AN, Sevdalis N, Vincent CA. Measuring intra-operative interference from distraction and interruption observed in the operating theatre. Ergonomics 2006;49:589–604, doi:http://dx.doi.org/10.1080/00140130600568899.
24. Catchpole KR, Giddings AEB, Wilkinson M, Hirst G, Dale T, de Leval MR. Improving patient safety by identifying latent failures in successful operations. Surgery 2007;142:102–10, doi:http://dx.doi.org/10.1016/j.surg.2007.01.033.
25. De Leval MR, Farewell VT. Thoracic and cardiovascular surgery human factors and cardiac surgery: a multicenter study. J Thorac Cardiovasc Surg 2000;119:661–72, doi:http://dx.doi.org/10.1067/mtc.2000.104868.