Visual attention on a respiratory function monitor during simulated neonatal resuscitation: an eye-tracking study

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ABSTRACT

Objective A respiratory function monitor (RFM) may improve positive pressure ventilation (PPV) technique, but many providers do not use RFM data appropriately during delivery room resuscitation. We sought to use eye-tracking technology to identify RFM parameters that neonatal providers view most commonly during simulated PPV.

Design Mixed methods study. Neonatal providers performed RFM-guided PPV on a neonatal manikin while wearing eye-tracking glasses to quantify visual attention on displayed RFM parameters (ie, exhaled tidal volume, flow, leak). Participants subsequently provided qualitative feedback on the eye-tracking glasses.

Setting Level 3 academic neonatal intensive care unit.

Participants Twenty neonatal resuscitation providers.

Main outcome measures Visual attention: overall gaze sample percentage; total gaze duration, visit count and average visit duration for each displayed RFM parameter. Qualitative feedback: willingness to wear eye-tracking glasses during clinical resuscitation.

Results Twenty providers participated in this study. The mean gaze sample captured wa s 93% (SD 4%). Exhaled tidal volume waveform was the RFM parameter with the highest total gaze duration (median 23%, IQR 13–51%), highest visit count (median 5.17 per 10 s, IQR 2.82–6.16) and longest visit duration (median 0.48 s, IQR 0.38–0.81 s). All participants were willing to wear the glasses during clinical resuscitation.

Conclusion Wearable eye-tracking technology is feasible to identify gaze fixation on the RFM display and is well accepted by providers. Neonatal providers look at exhaled tidal volume more than any other RFM parameter. Future applications of eye-tracking technology include use during clinical resuscitation.

INTRODUCTION

Positive pressure ventilation (PPV) is the cornerstone of neonatal resuscitation[1] but is technically challenging in preterm infants after birth. Mask leak and airway obstruction are common during PPV and lead to inadequate (too small) inflations. Conversely, many providers deliver excessive inflations, which contribute to acute lung injury.[2] There are few tools in the delivery room to identify these impediments, and neonatal providers' subjective assessment of PPV is poor.[2–5]

A respiratory function monitor (RFM) uses an in-line flow sensor between the gas flow and facemask to calculate and display data on delivered inflations during PPV. Typical parameters displayed on an RFM include flow, tidal volumes and pressure; these are displayed in both numeric and waveform format. Using a RFM improves the quality of PPV performed in a simulated environment.[6]

While the RFM improves PPV technique in simulation, little is known about how providers use the RFM to guide clinical neonatal resuscitation.[6–8] In an audit of clinical resuscitations with a visible RFM, the majority of providers reported that they did not use RFM data to inform their resuscitative efforts.[9] Other investigators found that many providers incorrectly interpret the presented RFM data.[10] One potential reason for this is that the standard RFM display is complex, with up to seven numeric values and four waveforms presented. In addition, it is possible that providers do not use the RFM because of the added cognitive burden during a high-stress clinical resuscitation. A key knowledge gap is that we do not know which displayed RFM parameters neonatal providers use most when performing PPV.

Wearable eye-tracking glasses provide the ability to ascertain and classify the wearer's focus of visual attention.[11–13] Eye tracking has been used in other medical fields to assess differences in gaze behaviour

What is already known on this topic?

► A respiratory function monitor (RFM) may improve the quality of positive pressure ventilation (PPV) performed by neonatal resuscitation providers.
► Many providers do not use the displayed RFM data appropriately to guide PPV during clinical delivery room resuscitation.
► The RFM parameters that are most useful to neonatal providers have not been defined.

What this study adds?

► Wearable eye-tracking technology provides a feasible method to identify regional gaze fixation on the RFM display and is well accepted by neonatal providers.
► Providers spend more time looking at exhaled tidal volume waveform data than any other RFM parameter to guide PPV.

between trainee and expert surgeons[13] [14] and to evaluate and quantify expertise in radiologists performing ultrasound-guided regional anaesthesia.[15] Eye tracking may also have application in the delivery room setting to identify how providers visually attend to the available monitors during neonatal resuscitation. To date, the only published delivery room eye-tracking study was a small pilot (n=6) that did not focus on the RFM.[16]

The objective of this simulation study was to assess the feasibility of wearable eye-tracking technology to identify neonatal providers' visual attention patterns on the RFM display when performing simulated PPV. Our second objective was to determine neonatal providers' assessment of the acceptability of wearable eye-tracking glasses in a clinical setting.

METHODS
Study design and population
This was a prospective observational study conducted at the Hospital of Pennsylvania, an academic level 3 neonatal intensive care unit[17] between 1 April 2016 and 31 December 2016. Twenty neonatal providers who were trained in the Neonatal Resuscitation Programme and routinely perform PPV for preterm infants during delivery room resuscitation volunteered to participate. We excluded providers who require corrective glasses and do not wear contact lenses or are unable to see within a two feet visible range without glasses. At the time of this study, the RFM was not routinely used during clinical resuscitation in our hospital. The study team provided study information packets and obtained verbal consent from all participants.

Equipment
Manikin
A Laerdal Resusci baby manikin (Laerdal, Stavanger, Norway) was modified by removing the lung and stomach bags and positioning a test lung within the chest cavity. The test lung was connected to the manikin's mouth with an endotracheal tube, and the system was confirmed to be leak free using the RFM.

RFM and respiratory equipment
RFM measurements were made with the New Life Box Respiratory Function Monitor (Advanced Life Diagnostics, Weener, Germany). The New Life Box uses an in-line sensor (Avea VarFlex Flow Transducer: CareFusion, Yorba Linda, California, USA), which placed in line between the T-piece infant resuscitator (Neopuff: Fisher and Paykel Healthcare, Auckland, New Zealand) and facemask (Vital Signs Size 2 infant face mask, CareFusion). The sensor is a pneumotachometer that detects pressure before and after the orifice in order to measure gas flow to and away from the manikin. The RFM integrates these signals to display the following parameters: flow, peak inspiratory pressure and positive end-expiratory pressure, inspiratory and expiratory tidal volume, mask leak and respiratory rate. These are displayed using both waveform and numeric format (figure 1). The initial Neopuff settings were peak inspiratory pressure of $20\,cm\,H_2O$, positive end-expiratory pressure of $5\,cm\,H_2O$, using a flow rate of 8–10 L/min.
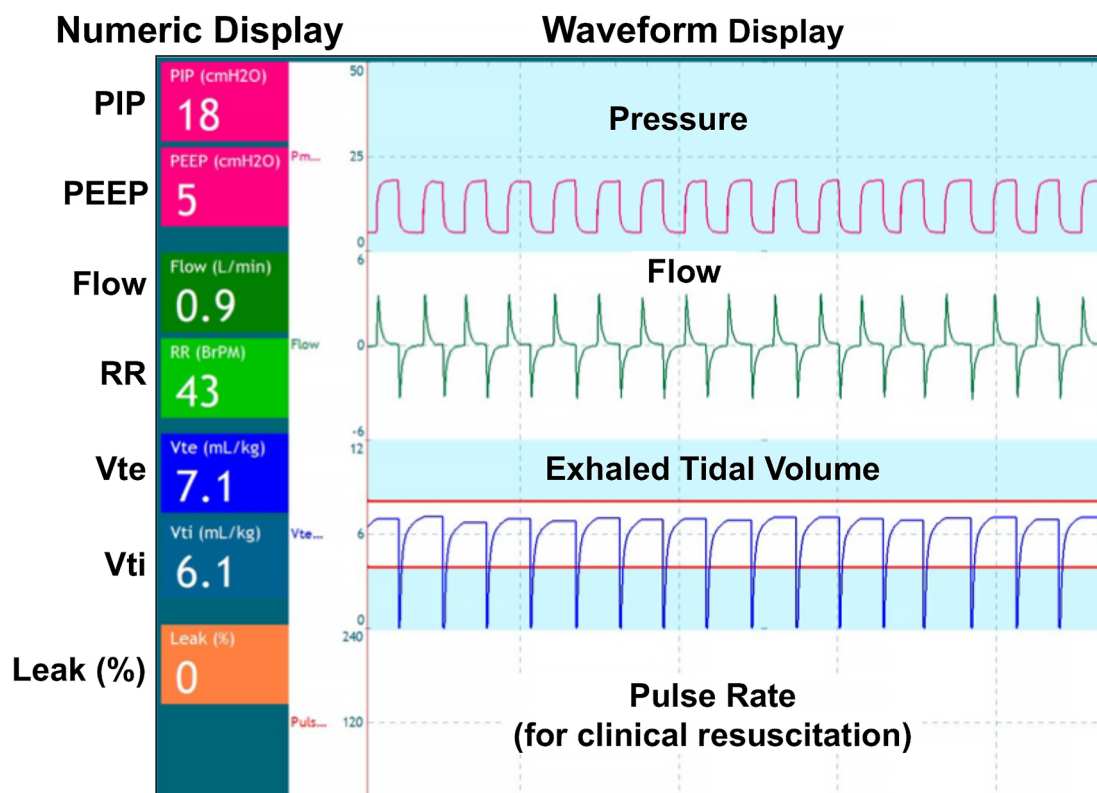

Figure 1 NewLife Box Respiratory Function Monitor Display (reproduced by permission, NewLifeBox Neo-RSD). Numeric data displayed on the left side of the screen include: peak inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), flow, respiratory rate (RR), exhaled tidal volume in mL/kg (Vte), inspiratory tidal volume in mL/kg (Vti) and mask leak (%). The numerical data are constantly refreshed and represent real-time values of each respiratory parameter at a specific point in time. Waveform data displayed include pressure, flow, exhaled tidal volume and pulse rate (using streaming pulse oximeter data during clinical resuscitation). The two horizontal orange lines in the Vte waveform region indicate 4 mL/kg and 8 mL/kg.

Eye-tracking glasses

We used the Tobii Pro Glasses 2 (Tobii Technology, Stockholm, Sweden, www.tobii.com), a light (45 grams) and non-obstructive headset (online Supplementary figure 1). An outward-facing scene camera captures the provider's visual field and a microphone records audio. Near infrared lights illuminate the pupils, and two cameras aimed at each eye capture the pupil diameter and movements at 50 Hz. The eye tracker measures characteristics of the user's eye and integrates them with an internal physiological 3D eye model to calculate the gaze data. Before each simulation, we ensured the participant's eyes were centred in each frame of the glasses and followed the manufacturer's calibration procedure. This process typically takes less than 30 s.

Procedure

The manikin was placed on a flat surface in front of the participants. The RFM was located directly behind the manikin in the providers' line of sight (online Supplementary figure 2). A study member read a standard script orienting the subjects to the RFM and provided visual aids with fixed screen shots of RFM displays of typical scenarios (ie, mask leak, airway obstruction). Participants had unlimited time to ask questions about the RFM display and interpretation but did not practice PPV using the RFM prior to starting the recording the session. Participants then performed PPV for 2 min using the RFM to target exhaled tidal volume between 4 and 8 mL/kg, ventilation rate of 40–60/min and mask leak <30%. During PPV, the participants could adjust their mask position and direct a study member to alter the pressure settings on the Neopuff based on their interpretation of the displayed RFM data.

Immediately after the simulation, the participants reviewed their recording with the study team in a semistructured think-aloud interview. The goals of the think aloud interview were to confirm the eye-tracking recording accurately reflected the participant's focus of visual attention, to determine the providers' thought process during the simulation, and to assess the participants' ability to correctly interpret and use the data presented on the RFM. In addition, we requested feedback on the eye-tracking glasses and asked providers if they would be willing to wear the eye-tracking glasses during clinical resuscitation. Verbal comments made during the simulation and interview were transcribed and coded for reference during data processing.

Data processing

We imported the eye-tracking recordings into Tobii Analyzer Pro and Tobii Pro Lab software (Tobii Technology, Stockholm, Sweden, www.tobii.com). The gaze data were automatically mapped onto an uploaded image of the RFM screen through the Tobii *Real World Mapping* process.[18] A member of the study team reviewed the accuracy of the locations of the gaze points placed by the automated *Real World Mapping*. Heat maps, graphical representation of the gaze data,[18] were generated for each participant to qualitatively demonstrate primary areas of visual attention (figure 2).

An area of interest (AOI) is a subregion of an image that is defined in the Tobii software. Gaze metrics are then calculated for each specified AOI. The RFM screen displays seven numeric values on the left and four central waveforms. We created 11 AOIs to represent these regions on an image of the RFM display. We also defined AOIs to represent the manikin and Neopuff.

Even following successful calibration of the eye-tracking glasses, it is possible to have a small but systematic offset between the actual and measured gaze location.[19] To account for

Figure 2 Example heat map. Heat maps are a graphical representation of the mapped gaze data, where colours indicate the density of gaze fixations (density increases from green-yellow-orange-red). Here the heat map demonstrates the summary of all gaze points on the respiratory function monitor (RFM) recorded during the simulation. These are mapped onto an exported image of the RFM screen. The highest density of gaze fixations, indicated by the red colour of the gaze point clusters, are seen overlying the exhaled tidal volume waveform region.

individual offsets in eye-tracking recordings,[19] we reviewed the videos, the verbalisations from the think-aloud interviews and the heat maps to customise the AOI borders for each participant (figure 3). The final processed data were exported using the raw gaze filter.[20]

Visual parameter outcomes

We assessed the gaze sample percentage across the entire recording. We measured the following visual attention parameters: total gaze duration, visit count and average visit duration (table 1). Not all recordings were exactly the same duration; therefore, absolute visit count was transformed into a rate per 10 s.

Data analysis

Using Stata V.14.0, we generated summary statistics for provider demographics and the visual attention parameters (total gaze duration, average visit duration and visit count).

Eye-tracking glasses cannot pick up gaze points in the periphery and therefore differential use of peripheral vision (based on height) could impact the gaze sample percentage.[21] Similarly, contact lenses could potentially affect the quality of data acquisition. We assessed the association between height and gaze sample percentage using Spearman's correlation and the association between contact lenses and gaze sample percentage using Wilcoxon rank sum test. A p value <0.05 was considered statistically significant.

RESULTS

Study participants had a mean age of 33 years; most (65%) were neonatal fellows (table 2). No providers had previous experience using a RFM to guide clinical resuscitation prior to participating in the study. Eye-tracking glasses captured a mean of 93% (SD 4%) of gaze samples. Gaze sample percentage was not significantly correlated with participant height (p=0.25), and there was no significant association between contact lens use and gaze sample percentage (p=0.57).
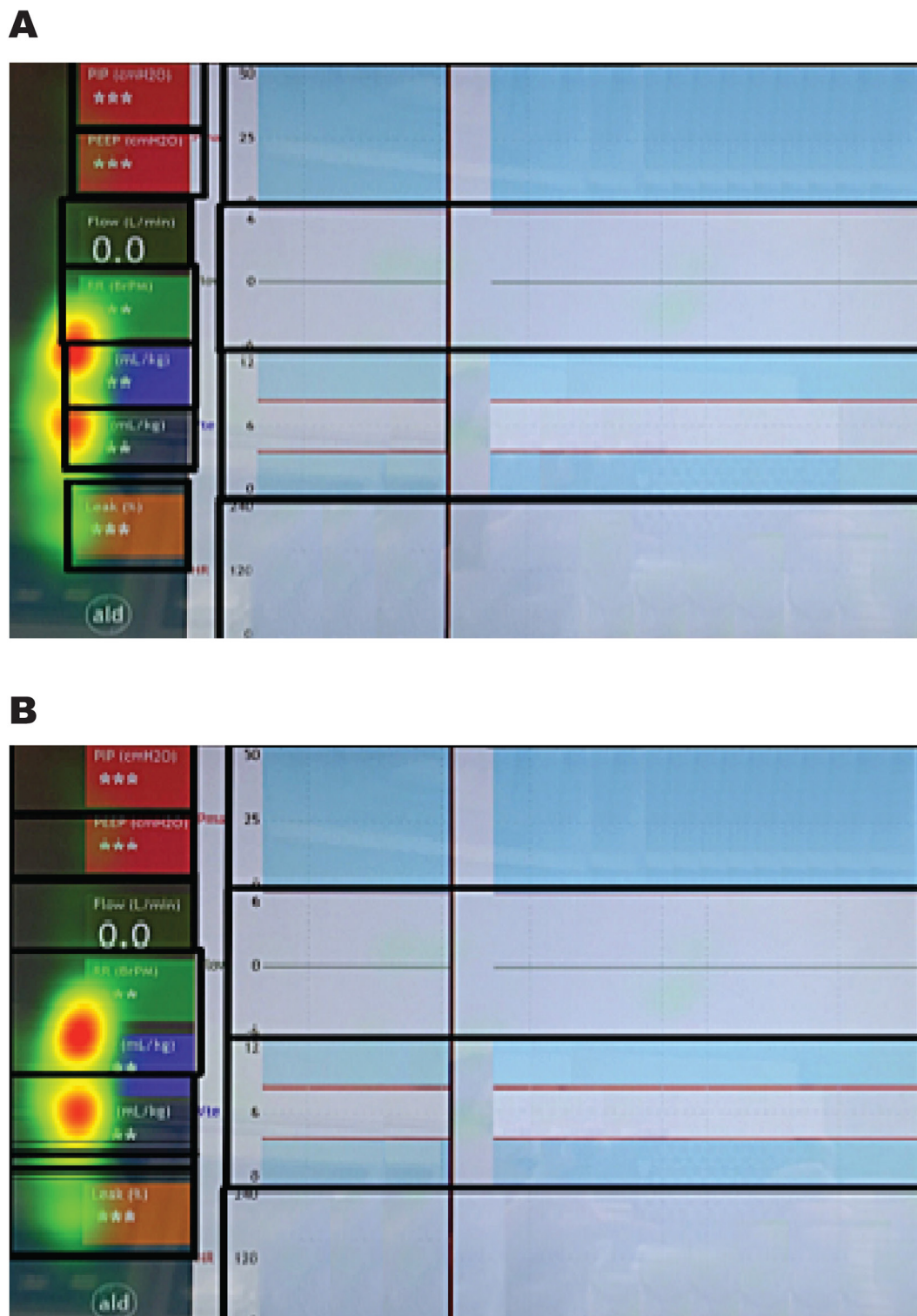
Figure 3 Systematic gaze offset. This heat map from a study participant demonstrates a systematic gaze offset. Areas of high gaze density are mapped to the left and downwards of the numeric respiratory parameters located on the left side of the respiratory function monitor (RFM) display. In (A), the original borders of the areas of interest (thick black borders) follow the natural rectangular boundaries of the displayed regions on the RFM screen, but these borders intersect the high gaze density regions displayed in the heat maps. In (B) the borders of the areas of interest are adjusted to accommodate the offset seen in the heat map.

The exhaled tidal volume waveform AOI had the highest gaze duration, visit count and average visit duration. The flow waveform, numeric respiratory rate and numeric leak AOIs were also commonly viewed (table 3). Cumulatively, providers looked at waveform parameters for a median of 33% of the simulation and numeric values for median of 20% of the simulation. The median total gaze duration was 6% (IQR 1%–15%) on the manikin and 0% (IQR 0%–1%) on the Neopuff.

In the think-aloud interview, participants qualitatively confirmed that the visual representation captured by the

Table 1 Visual attention parameters

Parameter	Description	Interpretation	Unit
Total gaze duration	Cumulative time each participant gazed on an area of interest, divided by the cumulative duration of gaze samples *	Where am I looking the most?	Percentage
Visit count	Number of visits within an area of interest per 10 s	How often am I looking at an area?	Rate
Average visit duration	Average time spent in an area of interest on a single visit	When I do look at an area, how much time am I spending in that area?	Seconds
Gaze sample percentage	Number of eye-tracking gaze points identified, divided by the theoretical maximum†	How much of my gaze data is truly captured?	Percentage

*The cumulative duration of gaze samples accounts for gaze sample percentage. That is, if the entire recording lasted 100 s, but the gaze sample percentage was only 90%, the cumulative duration of gaze samples was 90 s.

†The sampling frequency is 50 Hz, so the theoretical maximum is 50 samples per second. If the software adequately identifies all 50 gaze samples within each minute, the value of gaze sample percentage would be 100%. Blinking usually causes 5%–10% data loss.

eye-tracking glasses corresponded with their focus of cognitive attention during the simulation. Four subjects (20%) mentioned negative comments about the eye-tracking glasses, such as discomfort wearing the glasses or concern with dropping the eye-tracking equipment. Despite these reactions, all four of these participants were still willing to wear the glasses, and all 20 participants (100%) agreed they would be willing to wear eye-tracking equipment during clinical resuscitation in a code leader role.

DISCUSSION

We used a novel application of wearable eye-tracking technology to identify where neonatal providers focused their visual attention on a RFM display during simulated PPV. We found that resuscitators gazed for the longest duration and frequency on displayed waveforms, particularly exhaled tidal volume waveform. Participants evaluated the eye-tracking glasses positively and reported their willingness to wear them in a clinical setting.

Although respiratory function monitoring is an active line of investigation in delivery room research,[6–10] little is

Table 2 Demographic characteristics of participants

Characteristic	Participants (n=20)
Age (years), mean (SD) (range)	33.1 (2.23)
Female	13 (65%)
Height (cm), mean (SD)	170 (8.55)
Role	
Attending neonatologist	5
Neonatal fellow	13
Neonatal nurse practitioner	2
Clinical experience (years), mean (SD)	6 (2.09)
Visual aids	
Yes, contact lenses	9
Yes, glasses removed	2
No need for visual aids	9

known about how providers use the RFM clinically. In audit of preterm resuscitation, Schilleman et al found that few providers used the RFM data to guide PPV.[9] Conversely, it is possible that the RFM might distract providers from noticing and attending to other essential audiovisual cues.[22] Improving the usability of RFM displays could address both of these potential barriers. In this simulation study, we identified four respiratory parameters that were most commonly used by neonatal providers during PPV. These results could be applied to refining future design of RFMs to better display essential data. In addition, these findings could also inform training programmes to help providers use and interpret RFM data during resuscitation.

While this study provides preliminary findings regarding the salient regions of a RFM display, visual attention patterns likely differ during clinical resuscitation.[23] We acknowledge that additional areas of interest, such as the infant and other providers, may compete with the RFM and other physiological monitors during clinical resuscitation. The configuration of equipment and personnel in the delivery room could also impact the usability of the RFM clinically. In addition, added stress and cognitive burden during delivery room resuscitation may alter providers' visual attention patterns.[24] Law et al reported that visual attention on the infant differed between resuscitations based on the level of resuscitation interventions required.[16] As that study only reported on five subjects, it is unknown if these differences result from the increased cognitive burden of advanced resuscitation or simply represent interprovider variation. Ultimately, clinical studies are needed to assess whether and how providers use the RFM during delivery room resuscitation.

One limitation of eye-tracking technology is that visual attention does not necessarily indicate cognitive focus. Providers' eyes may have been fixated on a particular part of the RFM display while they were mentally processing separate information from other audio–visual cues. We addressed this by inviting participants to review their eye-tracking recording during the think-aloud interview; participants confirmed that their focus of cognitive attention corresponded with the recorded eye tracking gaze points. Another limitation is that automated gaze mapping with the Tobii software may have resulted in some lost mapped gaze points. Finally, we acknowledge that providers' behaviour and visual attention patterns may have been influenced by the targeted coaching they received during their orientation to the RFM.

Study strengths include creation of individual AOIs instead of standard AOIs for all participants to address systematic offsets in gaze data, consistent with other eye-tracking studies.[19] In addition, we conducted think aloud interviews to confirm the accuracy of eye-tracking data and assess whether the visual attention represented their focus of cognitive attention.

CONCLUSIONS

Wearable eye-tracking technology is a feasible method to identify regional gaze fixation on the RFM display and is acceptable to neonatal resuscitation providers. Resuscitators gazed at the waveform data, particularly that of exhaled tidal volume, longer and more frequently than the numeric values on the screen. These findings may hold relevance for designing RFM displays and training providers to use the RFM. Future applications of eye-tracking technology include defining visual attention patterns on the RFM during clinical resuscitation.

Original article

Table 3 Visual attention measurements for displayed parameters on the respiratory function monitor

Area of interest	Total gaze duration, median (IQR)	Visit count (rate per 10 s), median (IQR)	Average visit duration (s), median (IQR)
Exhaled tidal volume (waveform)	23% (13%–51%)	5.17 (2.82–6.16)	0.48 (0.38–0.81)
Flow (waveform)	9% (5%–22%)	3.22 (2.11–5.05)	0.29 (0.18–0.53)
Respiratory rate (number)	5% (2%–7%)	2.52 (1.34–3.85)	0.18 (0.12–0.28)
Leak (number)	5% (1%–11%)	1.92 (0.46–3.82)	0.27 (0.21–0.46)
Exhaled tidal volume (number)	3% (1%–8%)	2.02 (1.01–4.63)	0.17 (0.09–0.25)
Inspiratory tidal volume (number)	3% (1%–6%)	2.48 (0.59–4.50)	0.12 (0.07–0.23)
Positive end-expiratory pressure (number)	2% (1%–4%)	1.13 (0.39–2.32)	0.15 (0.12–0.21)
Flow (number)	2% (1%–4%)	1.48 (1.11–3.38)	0.14 (0.08–0.18)
Pulse rate (waveform)	1% (0%–1%)	1.61 (0.62–2.61)	0.05 (0.03–0.11)
Pressure (waveform)	0% (0%–3%)	0.70 (0.40–1.50)	0.07 (0.04–0.16)
Peak inspiratory pressure (number)	0% (0%–2%)	0.28 (0.14–1.45)	0.11 (0.05–0.23)

Competing interests None declared.

Patient consent Not required.

Ethics approval University of Pennsylvania Institutional Review Board.

Provenance and peer review Not commissioned; externally peer reviewed.

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