Matching design to use: a task analysis comparison of three cognitive aid designs used during simulated crisis management

Faire correspondre la conception à l'utilisation: une comparaison d'analyse de tâche de trois types d'aides cognitives utilisées pendant la gestion de crise en simulation

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Abstract

Purpose Intraoperative critical events typically include vital sign instability that requires a specific and time-sensitive response. Although cognitive aids can improve clinical performance during critical events, their design may not be optimized for real-world use. For example, during a critical event, health practitioners may be familiar with the treatment pathway and only require specific information from an aid—a behaviour described as “sampling”. We hypothesized that use of cognitive aids designed to facilitate sampling behaviour would reduce the time required to extract information during simulated critical events.

Methods We designed two experimental cognitive aids, based on cognitive science research on human performance, to facilitate sampling behaviour. Design principles included content clusters that were specifically located, colour-coded and labelled, the elimination of distractors such as numbering, and a key features

summary. In a simulated low-fidelity study, we compared the time required for anesthesia care providers to identify and extract specific information from these two experimental cognitive aids and from a traditional step-by-step “linear/control” aid. An eye-tracking device was used to assess how information was accessed from the cognitive aids.

Results When all response times were pooled, participants identified and extracted information more quickly using either experimental aid (median [interquartile range] 6.3 [4.0–9.7] sec, $P = 0.006$ and 4.7 [3.3–6.3] sec, $P < 0.001$) than the “linear/control” cognitive aid (12.7 [9.3–14.7] sec). Eye-tracking data revealed that participants spent more time looking at the “linear/control” design cognitive aid [mean (standard deviation) 10.9 (7.1) sec] than at either experimental cognitive aid [6.7 (4.6) and 3.8 (2.5) sec, $P = 0.020$, $P < 0.001$], respectively.

Conclusion Cognitive aids designed to enhance sampling behaviour may facilitate rapid retrieval of specific information during crisis management.

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Résumé

Objectif Les événements peropératoires critiques comportent, la plupart du temps, une instabilité des signes vitaux nécessitant une réponse à la fois spécifique et rapide. Bien que les aides cognitives puissent améliorer la performance clinique pendant les événements critiques, leur conception-même pourrait entraver leur utilisation optimale dans une situation concrète. Par exemple, pendant un événement critique, les professionnels de la santé pourraient bien connaître le protocole usuel de traitement et n'avoir besoin d'une aide cognitive que pour en tirer des informations spécifiques; ce type de comportement est décrit comme un « échantillonnage ».

Nous avons émis l'hypothèse que l'utilisation d'aides cognitives conçues de manière à faciliter les comportements d'échantillonnage réduirait le temps nécessaire à extraire l'information pertinente pendant des événements critiques simulés.

Méthode *Nous avons mis au point deux aides cognitives expérimentales en nous fondant sur les recherches en sciences cognitives sur la performance humaine afin de faciliter un comportement d'échantillonnage. Les principes de conception comprenaient des regroupements de contenu spécifiquement placés, à code couleur et étiquetés, l'élimination d'éléments distrayants tels que la numérotation, et un résumé des points clés. Dans une étude de simulation de basse fidélité, nous avons comparé le temps nécessaire au personnel d'anesthésie pour identifier et extraire des informations spécifiques de ces deux aides cognitives expérimentales et d'une liste traditionnelle, en format « linéaire/contrôle ». Un oculomètre a été utilisé pour évaluer la façon dont l'information était extraite des aides cognitives.*

Résultats *Lorsqu'on a regroupé tous les temps de réponse, les participants ont identifié et extrait les informations plus rapidement en utilisant l'une ou l'autre des aides cognitives expérimentales [écart interquartile] médian, 6,3 [4,0–9,7] sec, $P = 0,006$ et 4,7 [3,3–6,3] sec, $P < 0,001$) qu'avec l'aide cognitive « linéaire/contrôle » (12,7 [9,3–14,7] sec). Les données de l'oculomètre ont révélé que les participants passaient plus de temps à regarder l'aide cognitive de type « linéaire/contrôle » [(écart type) moyen 10,9 (7,1) sec] que l'une ou l'autre des aides cognitives expérimentales [6,7 (4,6) et 3,8 (2,5) sec, $P = 0,020$, $P < 0,001$, respectivement].*

Conclusion *Les aides cognitives conçues pour encourager le comportement d'échantillonnage pourraient faciliter la récupération rapide d'informations spécifiques pendant une gestion de crise.*

dose, identify additional treatment ideas or differential diagnoses, or verify that no important actions were missed.^{8,9} We have previously described such use of cognitive aids as “sampling” since only a fraction of the aid is used.¹⁰ Cognitive aids using a traditional linear design may not be optimal¹¹ for sampling behaviour.

Data from human factors and cognitive science research suggest that specific cognitive aid design elements may facilitate sampling behaviour and therefore improve retrieval of crucial information from the aid. These elements include “clustering,” or grouping of information into smaller subsections, organizing them so that each cluster shares a common thread, and consistently locating clusters in specific places on the visual aid. In addition, minimizing use of underlining, varying fonts/colours, and minimizing symbols that may be distractors also facilitates information retrieval.^{12,13} We used these principles^{14–21} to design two experimental cognitive aids for use during critical events. In addition, we designed a traditional step-by-step “linear/control” design cognitive aid that contained exactly the same information as the experimental cognitive aid. We then tested the effect of cognitive aid design on information retrieval during simulated low-fidelity critical event scenarios. Study subjects were asked to identify and extract specific information from the cognitive aid during three simulated clinical scenarios. We assessed the time required to successfully obtain information from the two experimental cognitive aids and from the “linear/control” cognitive aid. To understand how participants accessed the cognitive aids, we used an eye-tracking device that identified where they were looking during their interrogation of each cognitive aid. We hypothesized that participants would find specific information faster when using the experimental cognitive aids compared with a traditional “linear/control” aid.

Methods

Perioperative critical events play an important role in anesthesia-related mortality.¹ Such events may have a sudden onset and evolve rapidly or develop slowly with progressive patient deterioration.² During a critical event, clinical judgment and memory may be compromised by increased workload and stress,³ and use of cognitive aids such as checklists and emergency response manuals^{4–7} have been advocated to improve performance.

Traditionally, cognitive aids are formatted using a linear design, with the information listed in a step-by-step fashion from the top to the bottom of the aid. Nevertheless, rather than seeking step-by-step guidance, clinicians may use cognitive aids to obtain specific information such as a drug

This study was reviewed by the University of Chicago Institutional Review Board, which waived the requirement for written consent (Institutional Review Board 17-0216 designation February 2017). A convenience sample of anesthesia care providers was recruited (verbal consent) from an anesthesia department at an academic tertiary care medical centre and from a national pediatric anesthesia conference. To be considered as a study subject, participants had to be currently providing anesthesia care as an attending staff, resident, fellow, or certified registered nurse anesthetist (CRNA). No minimum anesthesia experience requirement was stipulated. Participants were informed that they would fill out surveys and participate in

the simulated use of cognitive aids. This manuscript adheres to the CONSORT guidelines.

Cognitive aid design

Because traditional cognitive aids utilize a linear, step-by-step design,^{22,23} we developed a “linear/control” version where tasks were numbered and listed in the order they were to be performed. With this “linear/control” design, drug doses, differential diagnostic possibilities, and treatment options were presented using a step-by-step format (see Figs 1a, 2a, 3a, 4a). We also designed two experimental cognitive aids to facilitate sampling behaviour using the principles of clustering, colour coding, and consistent content location (Table 1).^{14,15,17–21,24} One experimental “sampling” design (see Figs 1b, 2b, 3b, 4b), grouped content into six colour-coded blocks. Each block focused on a specific information category (initial actions, diagnoses, treatment options) and was located in the same location on the cognitive aid for all scenarios. Initial actions, likely to be accomplished even before looking at the aid, were grouped into the green “verify diagnosis—stabilize patient” block. Subsequent treatment actions were placed into the purple “treatment” block and differential diagnostic possibilities into the gold “differential (partial)” block. Drugs and dosages were placed either into the green “verify diagnosis—stabilize patient” or the purple “treatment” blocks in the order that they would typically be administered. To facilitate identification of drugs and dosages, we repeated drug information in a blue block labelled “drug/dosage summary”. Miscellaneous information was placed into an orange block, and “crisis management (if severe)” information was placed into a red block.

In a second experimental “sampling & key features” design (see Figs 1c, 2c, 3c, 4c) we used the same organization as the “sampling” design but added light gray summary boxes that contained key treatment issues or actions. This modification was specifically intended to facilitate evaluative sampling tasks, such as identifying additional treatment options or ensuring that no steps were missed. We placed these summaries along the far-left side of the page, next to the checklist actions and aligned them with relevant items in the green, purple, and gold blocks.

To further facilitate sampling behaviour, we used bullets rather than numbers to identify specific elements in our experimental aids. Numbering may orient healthcare providers to use the aid step-by-step or accomplish all lower-numbered items first and dissuade venturing out of a block to address more pressing challenges as appropriate during crisis management.

Each cognitive aid design was standardized to a one-page long format printed on white paper in landscape orientation (11" × 8 1/2"). The same information appeared on all cognitive aid designs for a given critical event.

Materials and equipment

Cognitive aids

We based the content of our cognitive aids on the American Society of Anesthesiologists (ASA) Guidelines,²⁵ textbooks,^{26,27} and existing aids previously created by the Department of Anesthesia Quality Assurance Committee at the University of Chicago. Cognitive aids in the three design formats described above (“linear/control”, “sampling”, and “sampling & key features”) were developed for one training scenario (bradycardia) and three test scenarios (anaphylaxis, hyperkalemia, local anesthetic systemic toxicity (LAST)). Twelve distinct cognitive aids were thus created: (1) anaphylaxis (Figs 1a, b, c); (2) bradycardia (Figs 2a, b, c); (3) hyperkalemia (Figs 3a, b, c); and (4) LAST (Figs 4a, b, c). During the pre-testing training session, design features of the various cognitive aids were pointed out to participants, but no instructions were provided as to how the aids should be utilized.

Scenarios

We created one training scenario and three test scenarios using a paper-based, low-fidelity design (see eTable 1: scenarios; available as electronic supplementary material [ESM]). All scenarios were based on real cases similar to those found in the ASA-sponsored Anesthesia Incident Reporting System database.²⁸ Each scenario, printed out on a sheet of paper, briefly described a patient undergoing surgery, the onset of symptoms associated with a critical event, and what actions the healthcare provider had already undertaken. Each scenario then directed the participant to use the cognitive aid to extract scenario-specific information regarding: 1) treatment (bradycardia); 2) drug dose (hyperkalemia); 3) additional treatment options (anaphylaxis); 4) differential diagnosis (LAST).^{8,10,29} The bradycardia scenario was used for training purposes only and data from that session were not included in our analysis.

Pre- and post-test surveys

Participants were surveyed before and after the simulated scenarios. Pre-test questions included asking participants about real or simulated critical events they had experienced during the preceding six months that could have been

1 Anaphylaxis

- 1 Verify Anaphylaxis, may have: tachycardia, hypotension, rash, bronchospasm
- 2 Give 100% O₂, evaluate ventilation
- 3 Remove suspected trigger(s)
 - If latex is suspected, thoroughly wash area, have surgeons change to non-latex gloves
 - If HYPotensive, turn off anesthetic agents
- 4 If decreased intravascular volume: infuse LR 1 L *rapidly*, may need 5-10 L
- 5 If hypotension and bronchospasm: give Epinephrine 10-100 MICROgrams IV, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min
- 6 If hypotension refractory to epinephrine: give vasopressin 1-2 units IV, repeat as needed
- 7 If bronchospasm: give albuterol 4-10 puffs or more as needed
- 8 If mediator release: give hydrocortisone 100 mg IV
- 9 If histamine release: give diphenhydramine 50 mg IV *and* famotidine 20 mg IV
- 10 If severe crisis:
 - Notify surgeon, call for help and code cart
 - Check pulse. If no pulse or HR<30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (pager #1234)
- 11 Differential diagnosis (partial):
 - Fat, thrombotic, cement, amniotic fluid embolus: See air embolus protocol
 - Sepsis: Support BP, give antibiotics
 - Myocardial Ischemia: give Morphine, oxygen, aspirin, NTG, beta-blocker, heparin

Common CAUSATIVE Agents

- IV Contrast
- Antibiotics
- Latex
- Neuromuscular blockers
- Chlorhexadine prep solution

Anaphylaxis

(a)

'Linear/
Control'

1 Anaphylaxis

VERIFY DX - STABILIZE PATIENT

- Verify Anaphylaxis, may have: Tachycardia, hypotension, rash, bronchospasm
- Give 100% O₂, evaluate ventilation
- Remove suspected trigger(s)
 - If latex is suspected, thoroughly wash area, have surgeons change to non-latex gloves
 - If HYPotensive, turn off anesthetic agents

DRUG / DOSAGE SUMMARY

- **Epinephrine** 10-100 MICROgrams IV, may need infusion 0.02-0.2 MICROgrams/kg/min IV
- **Vasopressin** 1-2 units IV
- **Albuterol** 4-10 puffs or more if needed
- **Hydrocortisone** 100 mg IV
- **Diphenhydramine** 50 mg IV
- **Famotidine** 20 mg IV

TREATMENT

Address ALL That Apply:

Cause	Action
Decreased intravascular volume	• LR 1 L IV <i>rapidly</i> , may need 5-10 L
Hypotension Bronchospasm	• Epinephrine 10-100 MICROgrams IV, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min
Hypotension refractory to epinephrine	• Vasopressin 1-2 Units IV, repeat as needed
Bronchospasm	• Albuterol 4-10 puffs or more as needed
Mediator release	• Hydrocortisone 100 mg IV
Histamine release	• Diphenhydramine 50 mg IV <i>and</i> famotidine 20 mg IV

DIFFERENTIAL (partial)

Fat, thrombotic, cement, amniotic fluid embolus	• See air embolus protocol
Sepsis	• Support BP, antibiotic
Myocardial Ischemia	• Morphine, oxygen, aspirin, NTG, beta-blocker, heparin

Common CAUSATIVE Agents

- IV contrast
- Antibiotics
- Latex
- Neuromuscular blockers
- Chlorhexadine prep solution

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If no pulse or HR<30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (pager #1234)

Anaphylaxis

(b)

'Sampling'

1 Anaphylaxis

	VERIFY DX - STABILIZE PATIENT <ul style="list-style-type: none"> • Verify Anaphylaxis, may have: tachycardia, hypotension, rash, bronchospasm • Give 100% O₂, evaluate ventilation • If HYPotensive <ul style="list-style-type: none"> • Turn off anesthetic agents • LR 1 L IV rapidly, may need 5-10 L • Epinephrine 10-100 MICROgrams IV, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min IV • If refractory to epi, give vasopressin 1-2 Units IV, repeat as needed 	DRUG / DOSAGE SUMMARY <ul style="list-style-type: none"> • Epinephrine 10-100 MICROgrams IV, may need infusion 0.02-0.2 MICROgrams/kg/min IV • Vasopressin 1-2 units IV • Albuterol 4-10 puffs or more if needed • Hydrocortisone 100 mg IV • Diphenhydramine 50 mg IV • Famotidine 20 mg IV 	
Ventilation			
Fluid and vasopressors			
	TREATMENT Address ALL That Apply: <ul style="list-style-type: none"> • Remove suspected trigger(s) • If latex is suspected, thoroughly wash area, have surgeons change to non-latex gloves 	Common CAUSATIVE Agents <ul style="list-style-type: none"> • IV contrast • Antibiotics • Latex • Neuromuscular blockers • Chlorhexadine prep solution 	
Remove triggers			
Treat bronchospasm	<ul style="list-style-type: none"> • Albuterol 4-10 puffs or more as needed 		
↓ Histamine & mediator release	<ul style="list-style-type: none"> • Hydrocortisone 100 mg IV • Diphenhydramine 50 mg IV <i>and</i> famotidine 20 mg IV 		
Consider other causes	DIFFERENTIAL (Partial) <ul style="list-style-type: none"> • Fat, thrombotic, cement, amniotic fluid embolus: See air embolus protocol • Sepsis: Support BP, antibiotics • Myocardial Ischemia: Morphine, oxygen, aspirin, NTG, beta-blocker, heparin 	CRISIS MANAGEMENT (If Severe) <ul style="list-style-type: none"> • Notify surgeon, call for help and code cart • Check pulse. If no pulse or HR<30: <ul style="list-style-type: none"> • Start chest compressions • Give epinephrine 100-1000 MICROgrams IV • If cardiac arrest, See cardiac arrest protocol • Consider ECMO (pager #1234) 	

Anaphylaxis

(c)

'Sampling
&
Key
Features'

Fig. 1 Cognitive aid designs, anaphylaxis scenario a “Linear/control” design b “Sampling” design c “Sampling & key features” design

2 Bradycardia/Pacing

- 1 Verify Bradycardia: ↓ HR ↓ BP with clinical evidence of poor perfusion
- 2 Give 100% O₂, evaluate ventilation
- 3 Consider: Atropine 0.2-0.4 mg IV or Glycopyrrolate 0.2-0.4 mg IV (4-7 min onset)
- 4 If surgical stimulation (vagal):
 - If laparoscopic, de-sufflate
 - If not laparoscopic, stop surgery
- 5 If high spinal: Intubate, ventilate, support HR and BP
- 6 If external/internal pacer failure: Contact electrophysiology (pager #1111)
- 7 If cardiac arrest: See cardiac arrest protocol
- 8 If myocardial ischemia: O₂, NTG, morphine, beta-blockers (when tolerated), consider risks/benefits of aspirin, clopidogrel if acute coronary syndrome
- 9 If Beta-blocker overdose:
 - Atropine 0.2-0.4 mg IV
 - Glucagon 5 mg IV
 - Check glucose
- 10 If Ca-channel blocker overdose:
 - Atropine 0.2-0.4 mg IV
 - Calcium chloride 1 g IV or
 - Calcium gluconate 1-2 g IV
 - If ineffective, glucagon 5 mg IV
- 11 For crisis management (if severe)
 - Notify surgeon, call for help and code cart
 - Check pulse. If no pulse or HR<30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (pager #1234)
- 12 Differential diagnosis (partial):
 - Monitor error: Check manual pulse
 - Junctional rhythm: Evaluate for cause

Instructions for PACING

1. Call for Pacer/Defibrillator
2. Place pacing ECG electrodes and pacer pads on chest.
3. Turn monitor/defibrillator ON, set to PACER mode
4. Set PACER RATE (ppm) to desired rate/min (80)
Can be adjusted up or down based on clinical response once pacing is established
5. Increase the PACER OUTPUT (mA) until electrical capture
Pacer spikes aligned with QRS complex. Threshold normally 65-100mA
6. Set PACER OUTPUT to 10mA above this level
7. Confirm pulse is present. If not, repeat steps 4-5

Bradycardia/Pacing

(a)
'Linear/
Control'

2 Bradycardia/Pacing

VERIFY DX – STABILIZE PATIENT

- Verify Bradycardia: ↓ HR ↓ BP with clinical evidence of poor perfusion
- Give 100% O₂, evaluate ventilation
- Consider
 - Atropine 0.2-0.4 mg IV or
 - Glycopyrrolate 0.2-0.4 mg IV (4-7 min onset)

TREATMENT

Select Cause	Action
Surgical stimulation (vagal)	<ul style="list-style-type: none"> • If laparoscopic, de-sufflate • If not laparoscopic, stop surgery
High spinal	<ul style="list-style-type: none"> • Intubate, ventilate, support HR and BP
External/internal pacer failure	<ul style="list-style-type: none"> • Contact electrophysiology (pager #1111)
Cardiac arrest	<ul style="list-style-type: none"> • See cardiac arrest protocol
Myocardial ischemia	<ul style="list-style-type: none"> • O₂, NTG, morphine, beta-blockers (when tolerated), consider risks/benefits of aspirin, clopidogrel if acute coronary syndrome
Beta-blocker overdose	<ul style="list-style-type: none"> • Atropine 0.2-0.4 mg IV • Glucagon 5 mg IV • Check glucose
Ca-channel blocker overdose	<ul style="list-style-type: none"> • Atropine 0.2-0.4 mg IV • Calcium chloride 1 g IV or • Calcium gluconate 1-2 g IV • If ineffective, glucagon 5 mg IV

DIFFERENTIAL (partial)

Monitor error	Check manual pulse
Junctional rhythm	Evaluate for cause

DRUG / DOSAGE SUMMARY

- Atropine 0.2-0.4 mg IV
- Calcium chloride 1 g IV
- Calcium gluconate 1-2 g IV
- Epinephrine 100-1000 MICROgrams IV
- Glucagon 5 mg IV
- Glycopyrrolate 0.2-0.4 mg IV

Instructions for PACING

1. Call for Pacer/Defibrillator
2. Place pacing ECG electrodes and pacer pads on chest.
3. Turn monitor/defibrillator ON, set to PACER mode
4. Set PACER RATE (ppm) to desired rate/min (80)
Can be adjusted up or down based on clinical response once pacing is established
5. Increase the PACER OUTPUT (mA) until electrical capture
Pacer spikes aligned with QRS complex. Threshold normally 65-100mA
6. Set PACER OUTPUT to 10mA above this level
7. Confirm pulse is present. If not, repeat steps 4-5

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If no pulse or HR<30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
- Consider transcutaneous pacing (see inset)
- If cardiac arrest, See cardiac arrest protocol
- Consider ECMO (pager #1234)

Bradycardia/Pacing

(b)
Figure 2b
'Sampling'

2 Bradycardia/Pacing

VERIFY DX – STABILIZE PATIENT

- Verify Bradycardia: ↓ HR ↓ BP with clinical evidence of poor perfusion
- Give 100% O₂, evaluate ventilation
- Consider
 - Atropine 0.2-0.4 mg IV or
 - Glycopyrrolate 0.2-0.4 mg IV 4-7 min onset

TREATMENT

Select Cause	Action
Surgical stimulation (vagal)	<ul style="list-style-type: none"> • If laparoscopic, de-sufflate • If not laparoscopic, stop surgery
High spinal	<ul style="list-style-type: none"> • Intubate, ventilate, support HR and BP
External/internal pacer failure	<ul style="list-style-type: none"> • Consider external pacer, contact electrophysiology (pager #1111)
Cardiac arrest	<ul style="list-style-type: none"> • See cardiac arrest protocol
Myocardial ischemia	<ul style="list-style-type: none"> • O₂, NTG, morphine, beta-blockers (when tolerated), consider risks/benefits of aspirin, clopidogrel if acute coronary syndrome
Beta-blocker overdose	<ul style="list-style-type: none"> • Atropine 0.2-0.4 mg IV • Glucagon 5 mg IV • Check glucose
Ca-channel blocker overdose	<ul style="list-style-type: none"> • Atropine 0.2-0.4 mg IV • Calcium chloride 1 g IV or • Calcium gluconate 1-2 g IV • If ineffective, glucagon 5 mg IV

DIFFERENTIAL (Partial)

- Monitor error: check manual pulse
- Junctional rhythm: evaluate for cause

DRUG / DOSAGE SUMMARY

- Atropine 0.2-0.4 mg IV
- Calcium chloride 1 g IV
- Calcium gluconate 1-2 g IV
- Epinephrine 100-1000 MICROgrams IV
- Glucagon 5 mg IV
- Glycopyrrolate 0.2-0.4 mg IV

Instructions for PACING

1. Call for Pacer/Defibrillator
2. Place pacing ECG electrodes and pacer pads on chest.
3. Turn monitor/defibrillator ON, set to PACER mode
4. Set PACER RATE (ppm) to desired rate/min (80)
Can be adjusted up or down based on clinical response once pacing is established
5. Increase the PACER OUTPUT (mA) until electrical capture
Pacer spikes aligned with QRS complex. Threshold normally 65-100mA
6. Set PACER OUTPUT to 10mA above this level
7. Confirm pulse is present. If not, repeat steps 4-5

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If no pulse or HR<30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
- Consider transcutaneous pacing (see inset)
- If cardiac arrest, See cardiac arrest protocol
- Consider ECMO (pager #1234)

Bradycardia/Pacing

(c)
Figure 2c
'Sampling
&
Key
Features'

Fig. 2 Cognitive aid designs, bradycardia scenario a “Linear/Control” design b “Sampling” design c “Sampling & key features” design

3 Hyperkalemia

- 1 Verify Hyperkalemia. May have: $K^+ > 6$, ECG changes (see inset box)
- 2 Hyperventilate, give 100% O_2 , evaluate ventilation
- 3 Give calcium gluconate 1-2 g IV or calcium chloride 1 g IV for cardiac stabilization
 - If peripheral IV: visually confirm no infiltration while injecting
 - Flush tubing after calcium administration
- 4 Stop infusion of PRBCs
- 5 To temporize hyperkalemia:
 - Sodium bicarbonate 100 mEq IV
 - Albuterol 4-10 puffs through ETT or nebulized (10-20 mg in 4 mL saline)
 - Dextrose 25-50 g IV and Insulin 10 Units IV
 - Terbutaline 0.25 mg loading dose subcutaneously then 0.1-10 MICROgrams/kg/min IV
- 6 Remove K^+ (definitive treatment):
 - Furosemide 20-40 mg IV
 - Kalexate 15 g OG/NG
 - Dialysis (if needed)
- 7 If ongoing transfusion needed: tell blood bank need ↓ K^+ PRBCs
- 8 If severe crisis:
 - Notify surgeon, call for help and code cart
 - Check pulse. If no pulse or HR <30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)
- 9 Differential diagnosis (partial):
 - Air, fat, thrombotic, cement, embolus: see air embolus protocol
 - Anaphylaxis: See CARD 1 (anaphylaxis)
 - Local Anesthetic Systemic Toxicity: See CARD 4 (LAST)

ECG Manifestations (variably present)

- Tall peaked T waves
- Prolonged PR
- Wide QRS
- Heart block
- Sine wave
- Vfib
- Asystole

Hyperkalemia

(a)
'Linear/
Control'

3 Hyperkalemia

VERIFY DX – STABILIZE PATIENT

- Verify Hyperkalemia. May have: $K^+ > 6$, ECG changes (see orange box)
- Hyperventilate, give 100% O_2 , evaluate ventilation
- Give calcium gluconate 1-2 g IV or calcium chloride 1 g IV for cardiac stabilization
 - If peripheral IV, visually confirm no infiltration while injecting
 - Flush tubing after calcium administration

DRUG / DOSAGE SUMMARY

- Calcium gluconate or chloride 1-2 g IV
- Sodium bicarbonate 100 mEq IV
- Albuterol 4-10 puffs through ETT or nebulized (10-20 mg in 4 mL saline)
- Dextrose 25-50 g IV and Insulin 10 Units IV
- Terbutaline 0.25 mg loading dose subcutaneously then 0.1-10 MICROgrams/kg/min IV
- Furosemide IV 20-40 mg IV
- Kalexate 15 g OG/NG

TREATMENT	
Cause/Need	Action
Infusion of K^+	<ul style="list-style-type: none"> • Stop infusion of PRBCs
Temporize hyperkalemia	<ul style="list-style-type: none"> • Sodium bicarbonate 100 mEq IV • Albuterol 4-10 puffs through ETT or nebulized (10-20 mg in 4 mL saline) • Dextrose 25-50 g IV and Insulin 10 Units IV • Terbutaline 0.25 mg loading dose subcutaneously then 0.1-10 MICROgrams/kg/min IV
Remove K^+ (definitive treatment)	<ul style="list-style-type: none"> • Furosemide 20-40 mg IV • Kalexate 15 g OG/NG • Dialysis (if needed)
Ongoing transfusion need	<ul style="list-style-type: none"> • Tell blood bank need ↓ K^+ PRBCs

ECG Manifestations – variably present

- Tall peaked T waves
- Prolonged PR
- Wide QRS
- Heart block
- Sine wave
- V fib or asystole

DIFFERENTIAL (partial)	
Embolus: Air, fat, thrombotic, cement	• See air embolus protocol
Anaphylaxis	• See CARD 1 (anaphylaxis)
Local Anesthetic Systemic Toxicity	• See CARD 4 (LAST)

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If no pulse or HR <30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)

Hyperkalemia

(b)
'Sampling'

3 Hyperkalemia

VERIFY DX – STABILIZE PATIENT	
Ventilation	<ul style="list-style-type: none"> • Hyperventilate, give 100% O_2, evaluate ventilation
Cardiac stabilization	<ul style="list-style-type: none"> • Give calcium gluconate 1-2 g IV or calcium chloride 1 g IV <ul style="list-style-type: none"> • If peripheral IV, visually confirm no infiltration while injecting • Flush tubing after calcium administration
TREATMENT	
Address ALL That Apply:	
Stop K^+ infusion	<ul style="list-style-type: none"> • Stop infusion of PRBCs
Temporize hyperkalemia	<ul style="list-style-type: none"> • Sodium bicarbonate 100 mEq IV • Albuterol 4-10 puffs through ETT or nebulized (10-20 mg in 4 mL saline) • Dextrose 25-50 g IV and Insulin 10 Units IV • Terbutaline 0.25 mg loading dose subcutaneously then 0.1-10 MICROgrams/kg/min IV
Remove K^+ (definitive Tx)	<ul style="list-style-type: none"> • Furosemide 20-40 mg IV • Kalexate 15 g OG/NG • Dialysis (if needed)
Transfusion	<ul style="list-style-type: none"> • Tell blood bank need ↓ K^+ PRBCs
DIFFERENTIAL (Partial)	
Consider other causes	<ul style="list-style-type: none"> • Air, fat, thrombotic, cement embolus: See embolus protocol • Anaphylaxis: See CARD 1 (anaphylaxis) • Local Anesthetic Systemic Toxicity: See CARD 4 (LAST)

DRUG / DOSAGE SUMMARY

- Calcium gluconate or chloride 1-2 g IV
- Sodium bicarbonate 100 mEq IV
- Albuterol 4-10 puffs through ETT or nebulized (10-20 mg in 4 mL saline)
- Dextrose 25-50 g IV and Insulin 10 Units IV
- Terbutaline 0.25 mg loading dose subcutaneously then 0.1-10 MICROgrams/kg/min IV
- Furosemide IV 20-40 mg IV
- Kalexate 15 g OG/NG

ECG Manifestations – variably present

- Tall peaked T waves
- Prolonged PR
- Wide QRS
- Heart block
- Sine wave
- V fib or asystole

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If no pulse or HR <30:
 - Start chest compressions
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)

Hyperkalemia

(c)
'Sampling
&
Key
Features'

Fig. 3 Cognitive aid designs, hyperkalemia scenario a “Linear/control” design b “Sampling” design c “Sampling & key features” design

4 Local Anesthetic Systemic Toxicity

- 1 Verify Local Anesthetic Systemic Toxicity (LAST), may have:
 - CNS symptoms (may not occur): tinnitus, metallic taste, seizures
 - CV collapse: rhythm disturbance, altered consciousness
- 2 Give 100% O₂, evaluate ventilation, stop N₂O and volatiles
- 3 Stop local anesthetic
 - What was given? Drug, dose, site? Does this = a crisis or not?
 - If crisis, **request intralipid** (available in CCD block cart, DCAM block room, CLI carts, pharmacy)
- 4 Ensure adequate IV access, monitoring of continuous ECG, BP, and SaO₂
- 5 Avoid propofol, vasopressin, calcium channel blockers
- 6 If need for seizure suppression: give midazolam 2-8 mg IV
- 7 If hypotension: give epinephrine 10-100 MICROgrams IV/IO, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min
- 8 If arrhythmias: give amiodarone 150 mg IV over 10 min
- 9 If acidosis or hyperkalemia: draw serial ABGs, consider a-line. For hyperkalemia treatment, see CARD 3
- 10 If severe crisis:
 - Notify surgeon, call for help and code cart
 - Check pulse. If cardiac instability occurs:
 - Start chest compressions (lipid must circulate)
 - Give epinephrine 100-1000 MICROgrams IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)
- 11 Differential diagnosis (partial):
 - Embolus: Air, thrombotic, cement: see CARD 1 (air embolus)
 - Anaphylaxis: see CARD 2 (anaphylaxis)
 - Myocardial Ischemia: give morphine, aspirin, NTG, beta-blocker, heparin

Intralipid Dosing

- Bolus **Intralipid 20% 100 mL IV** over 1 minute (~1.5 mL/kg lean body weight). Repeat every 3-5 minutes, until hemodynamically stable
- Start infusion **0.25 mL/kg/min**, increase as needed to 0.5 mL/kg/min
- **Continue infusion for at least 10 min** after hemodynamic stability is restored
- Max dose of intralipid 20% is 10 mL/kg (3 250 mL bags) over first 30 min. If not responding, reconsider if other diagnosis or inadequate resuscitation

(a)
'Linear/
Control'

Local Anesthetic Systemic Toxicity

4 Local Anesthetic Systemic Toxicity

VERIFY DX – STABILIZE PATIENT

- Verify Local Anesthetic Systemic Toxicity (LAST), may have:
 - CNS symptoms (may not occur): tinnitus, metallic taste, seizures
 - CV collapse: rhythm disturbance, altered consciousness
- Give 100% O₂, evaluate ventilation, stop N₂O and volatiles
- Stop local anesthetic
 - What was given? Drug, dose, site? Is this a crisis or not?
 - If crisis, **request intralipid** (available in CCD block cart, DCAM block room, CLI carts, pharmacy)
- Ensure adequate IV access, monitoring of continuous ECG, BP, and SaO₂
- **Avoid** propofol, vasopressin, calcium channel blockers

TREATMENT

Address ALL That Apply:	Action
Need for seizure suppression	▪ Midazolam 2-8 mg IV
Hypotension	▪ Epinephrine 10-100 MICROgrams IV/IO, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min
Arrhythmias	▪ Amiodarone 150 mg IV over 10 min
Acidosis, hyperkalemia	▪ Draw serial ABGs, consider a-line ▪ Hyperkalemia tx, see CARD 3

DIFFERENTIAL (partial)

Embolus: Fat, air, thrombotic, cement	▪ See embolus protocol
Anaphylaxis	▪ See CARD 1 (anaphylaxis)
Myocardial Ischemia	▪ Morphine, aspirin, NTG, beta-blocker, heparin

DRUG / DOSAGE SUMMARY

- **Intralipid 20% 100 mL IV** over 1 min, repeat until stable (see orange box below)
- **Epinephrine 10-100 MICROgrams IV/IO**
- **Midazolam 2-8 mg IV**
- **Amiodarone 150 mg IV** over 10 min

Intralipid Dosing

- Bolus **Intralipid 20% 100 mL IV** over 1 minute (~1.5 mL/kg lean body weight). Repeat every 3-5 minutes, until hemodynamically stable
- Start infusion **0.25 mL/kg/min**, increase as needed to 0.5 mL/kg/min
- **Continue infusion for at least 10 min** after hemodynamic stability is restored
- Max dose of intralipid 20% is 10 mL/kg (3 250 mL bags) over first 30 min. If not responding, reconsider if other diagnosis or inadequate resuscitation

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If cardiac instability occurs:
 - Start chest compressions (lipid must circulate)
 - Give epinephrine 10-100 MICROgrams/dose IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)

(b)
'Sampling'

Local Anesthetic Systemic Toxicity

4 Local Anesthetic Systemic Toxicity

VERIFY DX – STABILIZE PATIENT

- Verify Local Anesthetic Systemic Toxicity (LAST), may have:
 - CNS symptoms (may not occur): tinnitus, metallic taste, seizures
 - CV collapse: rhythm disturbance, altered consciousness

Ventilation	▪ Give 100% O ₂ , evaluate ventilation, stop N ₂ O and volatiles
Stop local	▪ Stop local anesthetic <ul style="list-style-type: none"> • What was given? Drug, dose, site? Is this a crisis or not?
Request intralipid	▪ If crisis, request intralipid (available in CCD block cart, DCAM block room, CLI carts, pharmacy)
	▪ Ensure adequate IV access, monitoring of continuous ECG, BP, and SaO ₂
	▪ Avoid propofol, vasopressin, calcium channel blockers

TREATMENT

Address ALL That Apply:	Action
Suppress seizure	▪ Midazolam 2-8 mg IV
Hypotension	▪ Epinephrine 10-100 MICROgrams IV/IO, as needed, may need infusion 0.02-0.2 MICROgrams/kg/min
Arrhythmia	▪ Amiodarone 150 mg IV over 10 min
Treat acidosis & hyperkalemia	▪ Draw serial ABGs, consider a-line ▪ Hyperkalemia treatment, see CARD 3

DIFFERENTIAL (Partial)

Consider other causes	▪ Fat, air, thrombotic, cement embolus: See embolus protocol
	▪ Anaphylaxis: See CARD 1 (anaphylaxis)
	▪ Myocardial Ischemia: Morphine, oxygen, aspirin, NTG, beta-blocker, heparin

DRUG / DOSAGE SUMMARY

- **Intralipid 20% 100 mL IV** over 1 min, repeat until stable (see orange box below)
- **Epinephrine 10-100 MICROgrams IV/IO**
- **Midazolam 2-8 mg IV**
- **Amiodarone 150 mg IV** over 10 min

Intralipid Dosing

- Bolus **Intralipid 20% 100 mL IV** over 1 minute (~1.5 mL/kg lean body weight). Repeat every 3-5 minutes, until hemodynamically stable
- Start infusion **0.25 mL/kg/min**, increase as needed to 0.5 mL/kg/min
- **Continue infusion for at least 10 min** after hemodynamic stability is restored
- Max dose of intralipid 20% is 10 mL/kg (3 250 mL bags) over first 30 min. If not responding, reconsider if other diagnosis or inadequate resuscitation

CRISIS MANAGEMENT (If Severe)

- Notify surgeon, call for help and code cart
- Check pulse. If cardiac instability occurs:
 - Start chest compressions (lipid must circulate)
 - Give epinephrine 10-100 MICROgrams/dose IV
 - If cardiac arrest, See cardiac arrest protocol
 - Consider ECMO (page #1234)

(c)
'Sampling
&
Key
Features'

Local Anesthetic Systemic Toxicity

Cognitive Aid Designs, LAST Scenario

Fig. 4 Cognitive aid designs, local anesthetic systemic toxicity (LAST) scenario a “Linear/control” design b “Sampling” design c “Sampling & key features” design

Table 1 Human factors and cognition principles related to cognitive aid design that were applied to our experimental aids to support sampling

Humans are better able to cognitively and visually process large amounts of information when it is broken into smaller sections or groupings ^{18,19}
Information within a section or grouping is cognitively processed most easily when it shares something in common with the other information in that grouping ²⁰
Consistency in content organization and layout (i.e., location on the page) facilitates searching for information (once the rules for how content is organized and where it is located are understood) ²¹
Sufficient white space and minimized distractors improve humans' ability to read and process text-based information ¹⁵
Distractors in text-based material that reduce its readability and comprehensibility include underlining text and excessive use of different fonts and font sizes, colour, and symbols ¹⁵

related to the simulated scenarios of the present study. Post-test questions included asking participants about the usefulness of the practice training scenario and the realism of the simulated critical events scenarios (eTable 2: pre- and post-test surveys; available as ESM). Survey data were collected and managed using the Research Electronic Data Capture (REDCap) tool supported by a National Institutes of Health Clinical and Translational Science Award UL1TR000430 and hosted by the University of Chicago.³⁰

Eye-tracking

To determine where participants were looking while accessing the cognitive aids, we used monocular 120 Hz eye-tracking glasses (pupil labs) with a 640X480 pixel @120 frames per second sensor and an infrared camera for dark pupil tracking. The camera recorded video from the perspective of each participant's field of view, and eye movements were represented as a green dot on the video image (latency of 5.7 msec, 1–2 degrees of error).³¹ Eye-tracking glasses were calibrated for each participant.

Video data were analyzed frame-by-frame to determine how long participants spent looking at the cognitive aid before acquiring the relevant information. Participants were considered to be looking at the aid when the green dot was visible on the page. They were considered to have read a portion of the aid when the green dot was localized for a dwell time of at least 250 msec (eight frames), the minimum duration considered to be adequate for text comprehension.³² Participants' hands were visible on the video recording. Pointing with a finger for > 250 msec at a specific portion of the aid was interpreted as reading that portion. If eye fixation and finger-pointing data conflicted, finger-pointing data were used.

Testing of participants

All testing took place in a standardized empty conference room. Participants were studied one at a time in our tertiary care hospital (21 participants) or at a conference centre (2 participants). A single author (A.C.) recruited participants

and collected the data. Each participant sat at a desk and was provided with a standardized summary of the study procedure. The identical information was communicated to all participants. After the pre-test survey, participants were shown the three types of cognitive aid ("linear/control", "sampling", and "sampling & key features") for the training bradycardia session. The three types of cognitive aid for the bradycardia scenario were shown in a randomized order (random number generator). After reviewing all three aid types for the bradycardia scenario, each subject was then asked verbally to choose one type of cognitive aid to use for the bradycardia training scenario.

After completing the training scenario, participants were then presented with each of nine possible combinations of the three test scenarios (hyperkalemia, anaphylaxis, and LAST) and three cognitive aid designs ("linear/control", "sampling", and "sampling & key features"). To minimize a learning effect, the nine combinations were presented in a quasi-randomized fashion using a Latin square design modified such that no cognitive aid design style was presented twice in a row.³³ In the crisis management scenario stem, participants were told that they had already completed certain actions and were now using the cognitive aid to identify the correct drug dose (hyperkalemia), review other treatment options (anaphylaxis), or identify differential diagnostic possibilities (LAST). After reading each scenario (electronic supplemental material: scenarios) and the prescribed task, participants consulted the designated cognitive aid and a timer was started. The timer was stopped when participants stated aloud that they had found the required information. Participants were instructed to find the information as quickly as possible and were aware that they were being timed.

Statistical analysis

Our primary outcome was the time required to find the required information using the three cognitive aid designs. We used G*Power³⁴ to determine the appropriate sample size *a priori* for the primary outcome of a 3 × 3 repeated-

measures analysis of variance (ANOVA) using the following parameters: 1) effect size $f = 0.5$; 2) power = 0.8; and 3) significance level = 0.05. This alpha level was chosen without Bonferroni adjustment and gave us a sample size of 23. We chose an effect size of 0.5 to be consistent with a recently published study evaluating cognitive aid design.³⁵

Data were analyzed using SPSS (v. 23; Armonk, NY, USA), Stata SE (v. 14.2; College Station, TX, USA), and the Social Science Statistics calculator (web-based). The Shapiro-Wilk test was used to test for normality of distribution. The Wilcoxon Rank Sum and Kruskal-Wallis tests were used for analysis of the data concerning the overall time required to find the information and for the time taken to find the information for each scenario (data not normally distributed). A Bonferroni adjustment was used to control for performing these two primary analyses. Eye-tracking data were normally distributed and were analyzed using paired t tests. All reported P values are unadjusted.

Results

Participants

Seventeen anesthesia faculty members, three senior residents or fellows, and three CRNAs participated as study subjects (one faculty member and two CRNAs declined). Staff anesthesiologists and CRNAs had a mean (SD) experience of 11.2 yr (8.4) (range 1–17) and 14.7 yr (16.5) (range 1–33), respectively. Residents and fellows had a mean (SD) training of 4.3 yr (0.58) (range 4–5). All 23 participants completed all nine scenario/aid pairs (207 trials in total). Eye-tracking was attempted for all participants, partial eye-tracking data were obtained for 21 (91%) participants and 140 (74%) scenarios, and data sufficiently complete for analysis were obtained for 55/207 trials. Finger-pointing and eye-tracking data conflicted in 0.5% of trials.

Overall time to find required information

Individual scenario comparisons

For the treatment options (anaphylaxis) and correct drug dose (hyperkalemia) scenarios, participants using the “linear/control” cognitive aid found the information more slowly compared with when using the experimental “sampling,” or “sampling & key features” aids (Table 2). For the diagnostic possibilities (LAST) scenario, time to find the information did not differ between any of the three aids. When the two

experimental aids were compared, time to find the information was faster with the “sampling & key features” aid for the treatment options (anaphylaxis) scenario only (Table 2).

Pooled data comparisons

When all response times were pooled, participants using the “linear/control” cognitive aid found the information more slowly compared with when the experimental “sampling,” or “sampling & key features” aids were used (Table 2). These results remained significant when compared with the Bonferroni adjusted threshold of 0.025. For the pooled data no difference was observed between the two experimental sampling aids (Table 2).

When response times were pooled by scenario instead of aid type, we found that the time to find information for the treatment options (anaphylaxis) scenario was longer than for the correct drug dose (hyperkalemia) or other diagnostic possibilities (LAST) scenarios (Table 2).

Eye-tracking data

Eye-tracking data were available for 17 interactions with the “linear/control” aid, 19 interactions with the “sampling” aid, and 15 interactions with the “sampling & key features” aid (Table 3).

Individual scenario comparisons

For the treatment options (anaphylaxis) scenario, when seeking information from the aid, participants spent more time looking at the “linear/control” cognitive aid compared with either the “sampling” or “sampling & key features” cognitive aids and participants also spent more time looking at the “sampling” aid than at the “sampling & key features” aid (Table 3). Eye-tracking data did not differ for any other scenario.

Pooled data comparisons

When eye-tracking data were pooled, we found that participants seeking information from the aid spent more time looking at the “linear/control” cognitive aid compared with either the “sampling” or “sampling & key features” cognitive aids (Table 3). In addition, participants spent less time looking at the “sampling & key features” aid compared with the “sampling” aid.

Survey data

During the six-month period preceding the study, seven participants experienced an anaphylaxis-related critical

Table 2 Time to finding information by cognitive aid design and scenario

	Linear/control aid Time (sec) <i>n</i> = 23	Sampling aid Time (sec) <i>n</i> = 23	Sampling & key features aid Time (sec) <i>n</i> = 23	Average for scenario Time (sec)	Wilcoxon rank sum test for aids
Anaphylaxis scenario	16 [11–26]	12 [6–15]	5 [4–10]	11.7 [9–18]	<i>P</i> = 0.01 for linear/control vs sampling <i>P</i> < 0.001 for linear/control vs sampling & key features <i>P</i> = 0.03 for sampling vs sampling & key features
Hyperkalemia scenario	7 [4–15]	4 [2–5]	3 [2–5]	4.3 [3.3–8]	<i>P</i> < 0.001 for linear/control vs sampling <i>P</i> < 0.001 for linear/control vs sampling & key features <i>P</i> = 0.41 for sampling vs sampling & key features
LAST scenario	7 [4–11]	5 [3–6]	4 [2–6]	6 [3.7–11.7]	<i>P</i> = 0.13 for linear/control vs sampling <i>P</i> = 0.07 for linear/control vs sampling & key features <i>P</i> = 0.33 for sampling vs sampling & key features
Average for aid (pooled scenarios) Time (sec)	12.7 [9.3–14.7]	6.3 [4–9.7]	4.7 [3.3–6.3]	—	<i>P</i> = 0.006 for linear/control vs sampling <i>P</i> < 0.001 for linear/control vs sampling & key features <i>P</i> = 0.04 for sampling vs sampling & key features
Wilcoxon rank sum test for scenarios (pooled aids)	<i>P</i> < 0.001 for anaphylaxis vs hyperkalemia <i>P</i> = 0.002 for anaphylaxis vs LAST <i>P</i> = 0.12 for hyperkalemia vs LAST				—

Times are reported in seconds: median [IQR]. See text for details. A Bonferroni adjustment was used to control for performing the two primary analyses: average for aid (pooled scenarios) 1) “linear/control” vs “sampling” and 2) “linear/control” vs “sampling & key features”

event while caring for a patient or as part of educational simulation training, 11 experienced a real or simulated hyperkalemia-related critical event, and none experienced a LAST event. These experiences did not alter the effect of cognitive aid design on time to find the information ($P = 0.79$ and $P = 0.38$, respectively, two-tailed t tests). Participants also rated the utility of both the training and experimental scenarios highly (Table 4). A one-way ANOVA found no effect of the cognitive aid chosen for the practice scenario on the time to find the required information during the testing sessions (Table 5).

Discussion

Two experimental cognitive aids, designed to facilitate acquisition of specific information (“sampling” behaviour) enabled more rapid access of information during simulated critical events when compared with use of a step-by-step

“linear/control” cognitive aid. The experimental cognitive aids facilitated faster information acquisition during a spectrum of critical event scenarios that required different types of information for successful patient management. Eye-tracking data confirmed that participants seeking information spent more time searching the “linear/control” aid than either the “sampling” or “sampling & key features” aid. These data support our hypothesis that cognitive aids optimized for sampling behaviour facilitate the rapid retrieval of specific information during critical events.

Our findings add to existing literature regarding checklist use and design. A 2016 study of cognitive aid design and utility³⁵ found better team dynamics associated with use of a linear design compared with a branched “flow sheet” design. We did not assess a branched design aid as our focus was on the time taken to access specific information rather than to evaluate step-by-step event performance. Our study differs from the 2016 effort³⁵ in

Table 3 Eye-tracking data by scenario and aid

	Linear/control aid, <i>n</i> = 17 Time (sec)	Sampling aid, <i>n</i> = 19 Time (sec)	Sampling & key features aid, <i>n</i> = 15 Time (sec)	Paired <i>t</i> tests and pairwise differences for aids
Anaphylaxis scenario	15.8 (8.2)	7.9 (4.1)	4.4 (2.8)	Linear/control vs sampling <i>P</i> = 0.02 and -6.5 ± 2.45 (0.4 to -13.3) <i>P</i> = 0.58 Linear/control vs sampling & key features <i>P</i> = 0.006 and -11.2 ± 4.14 (0.4 to -22.7) <i>P</i> = 0.55 Sampling vs sampling & key features <i>P</i> = 0.045 and -4.7 ± 2.55 (2.4 to -11.8) <i>P</i> = 0.14
Hyperkalemia scenario	10.2 (6.9)	5 (4)	3.3 (3.3)	Linear/control vs sampling <i>P</i> = 0.06 and -4.6 ± 4.42 (9.4 to -18.7) <i>P</i> = 0.37 Linear/control vs sampling & key features <i>P</i> = 0.05 and -7.1 ± 3.78 (4.9 to -19.1) <i>P</i> = 0.16 Sampling vs sampling & key features <i>P</i> = 0.24 and -2.5 ± 0.65 (-0.4 to -4.6) <i>P</i> = 0.031
LAST scenario	7.7 (4.9)	7.5 (6.7)	3.5 (1.8)	Linear/control vs sampling <i>P</i> = 0.48 and 1.2 ± 5.13 (17.5 to -15.1) <i>P</i> = 0.83 Linear/control vs sampling & key features <i>P</i> = 0.06 and -2.8 ± 3.63 (8.8 to -14.3) <i>P</i> = 0.5 Sampling aid vs sampling & key features <i>P</i> = 0.12 and -3.9 ± 3.38 (6.8 to -14.7) <i>P</i> = 0.33
Average for aid Time (sec)	10.9 (7.1)	6.7 (4.6)	3.8 (2.5)	Linear/control vs sampling <i>P</i> = 0.02 and -5.0 ± 1.88 (-0.96 to -9.01) <i>P</i> = 0.019 Linear/control vs sampling & key features <i>P</i> < 0.001 and -8.18 ± 1.88 (-4.15 to -12.22) <i>P</i> < 0.001 Sampling vs sampling & key features <i>P</i> < 0.001 and 1.27 ± 1.27 (-0.47 to -5.93) <i>P</i> = 0.03

Times are reported in seconds and presented as mean (standard deviation). Pairwise differences are reported as mean difference $\pm$ standard error (95% confidence interval). See text for details

that we did not instruct participants on how to use the aids. In addition, our aids were developed to facilitate sampling behaviour. In surveys, clinicians report that they may access critical event cognitive aids only to “sample” or locate specific information.^{8,29} Our study also adhered to established principles of aid design including derivation from best practice, appropriateness for the scenario, clustering of information, and familiarity.³⁶⁻³⁹

As this study was done as a simulated crisis exercise, we can only speculate about the effect of cognitive aid design on real clinical performance. Nevertheless, our findings support the hypothesis that cognitive aid design may help clinicians to acquire needed information more efficiently. Such aids may be particularly useful where the general treatment strategy is known (such as for hyperkalemia) but specific information regarding treatment such as drug type

Table 4 Training usefulness and scenario realism ratings* ($n = 23$)

Question	Mean	SD
Training on the three different cognitive aid designs was helpful	82.09	18.77
Bradycardia practice exercise was useful	79.91	17.41
Anaphylaxis scenario was realistic	86.35	13.02
Hyperkalemia scenario was realistic	83.13	17.05
LAST scenario was realistic	79.35	17.70

*Ratings were made using a slider on a 100-point scale; higher ratings indicate greater agreement with the statement. LAST = local anesthetic systemic toxicity; SD = standard deviation

Table 5 Cognitive aid design chosen for the practice scenario and time to find required information during the testing sessions

Cognitive aid design chosen for the practice scenario	Average time to find required information during the testing sessions		
	Linear/control aid	Sampling aid	Sampling & key features aid
Linear/control aid $n = 2$	7.7 (3.8)	3.8 (1.2)	3.6 (1.4)
Sampling aid $n = 13$	13.2 (3.6)	6.6 (2.4)	6.9 (4.7)
Sampling & key features aid $n = 8$	12.3 (3.9)	10.5 (8.8)	5.3 (3.9)

Times reported in seconds, mean (standard deviation)

or dose is required. It is relevant that healthcare providers use cognitive aids inconsistently, and often do not find them useful.⁸ Although this behaviour is poorly understood, one possibility is that cognitive aids are not adequately designed for their intended purpose.⁴⁰ Our data provide a potential explanation.

Our results should be considered with regard to the specific crisis scenario and task. When times were pooled across aid types, we observed that the time to acquire information in the treatment options (anaphylaxis) scenario was longer compared with the correct dose (hyperkalemia) scenario. One possibility is that hyperkalemia was a more familiar problem to the study subjects. Another possibility is that the correct dose (hyperkalemia) scenario represented a different type of task. In the correct dose (hyperkalemia) scenario we asked participants to identify the correct dose of identified drugs (insulin and glucose). This “hunting” task primarily involved *recognition* and the cognitive tasks of perception and attention. In contrast, in the treatment options (anaphylaxis) scenario, participants had to identify an additional treatment idea. This “surveying” task was *evaluative*, which required the use of working memory. Evaluation takes more effort cognitively as the cognitive aid has to be compared with what has already occurred.²⁹ In contrast, *recognition* only requires enough information to be processed to determine whether each item is the target or not, and therefore takes less time.^{18,21} These data support the notion that “hunting” and “surveying” may represent two distinct types of tasks.

Our study has clear limitations. Because our study primarily involved one anesthesia department, our findings may not be generalizable to others providing anesthesia care. Importantly, we did not account for potential confounding variables such as level of training, years in practice, age, and sex. Testing took place at more than one location, which could be another potentially confounding variable. Participants were assigned tasks that could bias performance in favour of the experimental aid designs. More complex scenarios, for example, may or may not be better addressed using a step-by-step “linear/control” aid design. We acknowledge that performance was assessed during low-fidelity crisis scenarios, so the relevance of our findings with real life clinical care is unclear. Moreover, our study design simulated a solo healthcare provider model rather than a perioperative healthcare team. Current best practice guidelines advocate that health crisis management be team-based,^{35,37} and that the team members be familiar with the cognitive aids before relying on them in actual events.^{6,8,10}

The eye-tracking technology used in this study requires particular consideration. As the limit of eye-tracking is 1–2 visual degrees³¹ we could only localize participants’ gaze to 3–5 lines of text. Therefore it is possible that we misinterpreted where participants were actually looking. Variability in how the tracking device was worn and in lighting conditions (e.g., glare) may also have influenced our data. Although the eye-tracking data we report are consistent with those obtained in other studies,⁴¹ we

acknowledge that in more than 50% of participants the information was incomplete.

Human factors and cognitive science research have influenced the design of cognitive aids used in stressful and complex environments, such as aviation⁴² and medicine.⁵ Our findings add to the existing literature by demonstrating that incorporating specific cognitive aid design features is feasible and may facilitate efficient acquisition of crucial information during patient crisis management.

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References

- Li G, Warner M, Lang BH, Huang L, Sun LS. Epidemiology of anesthesia-related mortality in the United States, 1999-2005. *Anesthesiology* 2009; 110: 759-65.
- Sams SH, Revilla S, Stahl DL. Delayed development of malignant hyperthermia following cardiopulmonary bypass. *Semin Cardiothorac Vasc Anesth* 2018; 22: 95-9.
- Dismukes R, K Goldsmith TE, Kochan JA. Effects of Acute Stress on Aircrew Performance: Literature Review and Analysis of Operational Aspects. Moffett Field, CA: NASA Ames Research Center; 2015. NASA Techn Memo TM-2015-218930. Available from URL: https://www.researchgate.net/profile/Key_Dismukes2/publication/299578388_Effects_of_Acute_Stress_on_Aircrew_Performance_Literature_Review_and_Analysis_of_Operational_Aspects/links/56fff4a708aea6b77469b3b5/Effects-of-Acute-Stress-on-Aircrew-Performance-Literature-Review-and-Analysis-of-Operational-Aspects.pdf (accessed January 2019).
- Stanford Anesthesia Cognitive Aid Group [SACAG]. Emergency Manual: Cognitive aids for perioperative clinical events. Edition 3.1 Available from: <http://emergencymanual.stanford.edu> (accessed January 2019).
- Arriaga AF, Bader AM, Wong JM, et al. Simulation-based trial of surgical-crisis checklists. *N Engl J Med* 2013; 368: 246-53.
- Clebone A, Burian BK, Watkins SC, et al. The development and implementation of cognitive aids for critical events in pediatric anesthesia: The Society for Pediatric Anesthesia Critical Events Checklists. *Anesth Analg* 2017; 124: 900-7.
- Moitra VK, Gabrielli A, Maccioli GA, O'Connor MF. Anesthesia advanced circulatory life support. *Can J Anesth* 2012; 59: 586-603.
- Goldhaber-Fiebert SN, Pollock J, Howard SK, Bereiknyei Merrell S. emergency manual uses during actual critical events and changes in safety culture from the perspective of anesthesia residents: a pilot study. *Anesth Analg* 2016; 123: 641-9.
- Watkins SC, Anders S, Clebone A, et al. Paper or plastic? Simulation based evaluation of two versions of a cognitive aid for managing pediatric peri-operative critical events by anesthesia trainees: evaluation of the society for pediatric anesthesia emergency checklist. *J Clin Monit Comput* 2016; 30: 275-83.
- Burian BK, Clebone A, Dismukes RK, Ruskin KJ. More than a tick box. Medical checklist development, design, and use. *Anesth Analg* 2018; 126: 223-32.
- Catchpole K, Russ S. The problem with checklists. *BMJ Qual Saf* 2015; 24: 545-9.
- Hartley J. Eighty ways of improving instructional text. *IEEE Trans Prof Commun* 1981; 24: 17-27.
- Degani A. On the Typography of Flight-Deck Documentation. Moffett Field, CA: NASA Ames Research Center; 1992. NASA Techn Memo #177605, Contract NCC2-327. Available from URL: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930010781.pdf?source=techstories.org> (accessed January 2019).
- Barnett B. Aiding type and format compatibility for decision aid interface design. Proceedings of the 34th annual meeting of the Human Factors Society. Santa Monica, CA: Human Factors Society; 1990: 1552-6.
- Wickens CD, Hollands JG. Engineering Psychology and Human Performance. 3rd ed. Upper Saddle River, NJ: Prentice Hall; 2000 .
- American Society of Anesthesiologists. ASA Recommendations for Pre Anesthesia Checkout, 2008. Available from URL: <https://www.asahq.org/resources/clinical-information/2008-asa-recommendations-for-pre-anesthesia-checkout> (accessed January 2019).
- Lindsay PH, Norman DA. Human Information Processing. NY: Academic Press; 1972 .
- Sweller J, Chandler P, Tierney P, Cooper M. Cognitive load as a factor in the structuring of technical material. *J Exp Psychol* 1990; 119: 176-92.
- Rayner K. Eye Movements in Reading: Perceptual and Language Processes. Cambridge, MA: Academic Press; 1983 .
- Rumelhart D. Schemata: The building blocks of cognition. In: Spiro RJ, Bruce BC, Brewer WF, editors. Theoretical Issues in Reading Comprehension. Hillsdale, NJ: Lawrence Erlbaum Associates; 1980. p. 33-58.
- Solso RL. Cognitive Psychology. 5th ed. Boston, MA: Allyn and Bacon; 1998 .

22. *Society for Pediatric Anesthesia*. Pedicrisis Critical Event Cards. Available from URL: <http://www.pedsanesthesia.org/critical-events-checklist/> (accessed January 2019).
23. *Borshoff D*. The Anesthetic Crisis Manual: North American Edition. Lighthall G (Ed.). West Perth, AU: Leeuwin Press; 2013.
24. *Rumelhart D*. Human Information Processing. NY: Wiley; 1977 .
25. *American Society of Anesthesiologists*. Standards, Guidelines, and Related Resources. Available from URL: <https://www.asahq.org/quality-and-practice-management/standards-guidelines-and-related-resources-search> (accessed January 2019).
26. *Barash PG, Cullen BF, Stoelting RK, Cahalan MK, Stock MC, Ortega R*. Clinical Anesthesia. 7th ed. Philadelphia, PA: Lippincott; 2013 .
27. *Miller R, Cohen NH, Eriksson LI, Fleisher LA, Wiener-Kronish JP, Young WL*. Miller's Anesthesia. 8th ed. Philadelphia, PA: Saunders; 2014 .
28. *Anesthesia Quality Institutet*. AIRS Database Website. Available from URL: <https://qualityportal.aqihq.org/AIRSMain/AIRSSelectType/0> (accessed January 2019).
29. *Burian BK*. The Medical Checklist, Cognitive Aid, and Clinical Decision Support System Handbook. NY: Oxford University Press; 2019 .
30. *Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG*. Research electronic data capture (REDCap) – a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009; 42: 377-81.
31. *Kassner MP, Patera WR*. PUPIL: Constructing the Space of Visual Attention. Cambridge: Massachusetts Institute of Technology; 2012. Available from URL: <http://hdl.handle.net/1721.1/72626> (accessed January 2019).
32. *Raney GE, Campbell SJ, Bovee JC*. Using eye movements to evaluate the cognitive processes involved in text comprehension. *J Vis Exp* 2014; DOI: 10.3791/50780.
33. *Zeelenberg R, Pecher D*. A method for simultaneously counterbalancing condition order and assignment of stimulus materials to conditions. *Behav Res Methods* 2015; 47: 127-33.
34. *Faul F, Erdfelder E, Lang AG, Buchner A*. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007; 39: 175-91.
35. *Marshall SD, Sanderson P, McIntosh CA, Kolawole H*. The effect of two cognitive aid designs on team functioning during intra-operative anaphylaxis emergencies: a multi-centre simulation study. *Anaesthesia* 2016; 71: 389-404.
36. *Thorndyke PW*. Cognitive structures in comprehension and memory of narrative discourse. *Cogn Psychol* 1977; 9: 77-110.
37. *Marshall S*. The use of cognitive aids during emergencies in anesthesia: a review of the literature. *Anesth Analg* 2013; 117: 1162-71.
38. *Weiser TG, Berry WR*. Review article: perioperative checklist methodologies. *Can J Anesth* 2013; 60: 136-42.
39. *Frase LT, Schwartz BJ*. Typographical cues that facilitate comprehension. *J Educ Psychol* 1979; 71: 197-206.
40. *Merry AF, Mitchell SJ*. Advancing patient safety through the use of cognitive aids. *BMJ Qual Saf* 2016; 25: 733-5.
41. *McCormack C, Wiggins MW, Loveday T, Festa M*. Expert and competent non-expert visual cues during simulated diagnosis in intensive care. *Front Psychol* 2014; 5: 949.
42. *Degani A, Wiener EL*. Human factors of flight-deck checklists: The normal checklist. Moffett Field, CA: NASA Ames Research Center; 1990. NASA Contractor Report 177549. Available from URL: https://ti.arc.nasa.gov/m/profile/adegani/Flight-Deck_Checklists.pdf (accessed January 2019).

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