RapidRead: Step-At-A-Glance Crisis Checklists

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ABSTRACT
Complex, perilous domains like surgery and aviation require accurate responses under extreme time constraints. Checklists improve important outcomes in these domains. However, current designs are based largely on intuition; there is little theory or empirical work about designing effective procedure aids. Furthermore, discretionary checklist use is fragmented and bursty rather than predictable and continuous. Working with doctors and studying successful aids, we developed the *RapidRead* design approach. It distills three patterns for designing rapidly readable aids: Dynamic Focus, Object-Action, and Information Patches. Two experiments compared medical professionals' search time, eye-gaze, and retention with alternative checklist designs. Applying RapidRead patterns resulted in significantly faster aid usage, reducing answer time and importantly minimizing the frequency of slow responses to medical queries.

Author Keywords
Checklists; Medicine; Procedure aids

ACM Classification Keywords
H.5.2. User Interfaces: Screen design

INTRODUCTION
In U.S. hospitals, an estimated 400,000 deaths per year are associated with preventable harm, and serious complications may be ten to twenty times more common [20]. This harm is preventable through reduced errors and increased adherence to best practices [11,23]. In general, these errors are not caused by lack of skill or attentiveness, but rather cognitive overload [8,12].

Checklists have the opportunity for tremendous impact by helping people manage cognitive complexity [13]. Checklist use improves performance in aviation [2,3,9] and medicine, from surgery to intensive care and crisis response [1,13,16,17,26,30,38]. For example, introducing a routine checklist into Michigan hospitals decreased infection rates by 66%, saving about $175 million and more than 1500 lives, in the first 18 months [30].

Checklists also help as *cognitive aids* [37], reducing de-

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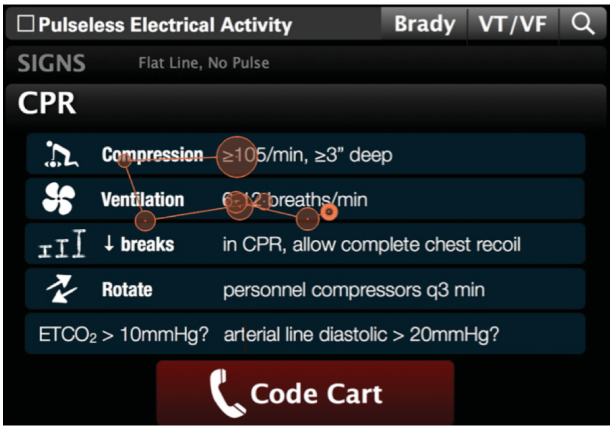

Figure 1: RapidRead patterns facilitate speed, with low-variance (that is, predictable) search times. An efficient gaze path is shown with circles and lines.

mand on short- [40] and long-term memory [16]. A shared reference that people point to grounds communication and improves team coordination [22]. Reading aids aloud makes explicit what is underway, encouraging situational awareness and a shared mental model [16]. Institutionally, aids can standardize tasks and improve protocol adherence [1,38], supporting quality control and process improvement.

However, checklists are not a panacea. An additional information source can add delay, attentional load, and complexity [13,36], leading to slower acceptance. As Verdaasdonk *et al*. [34] put it, "Time governs willingness and compliance in the use of checklists."

Work in aviation has focused on the importance of typography in making checklists easy and fast to read [10]. A checklist for medical checklists [14] provides guidelines such as using "fewer than 10 items per pause point". However, these guidelines have not been empirically validated.

Contributions
This paper contributes: 1) a formative set of comparative measurements of information finding tasks, and 2) The RapidRead design patterns found in these checklists that empirically improve performance on these tasks. No existing guidelines have been empirically tested, and there is little empirical work on comparing alternative layouts of information resources [10,14].

This paper presents two experiments comparing alternative layouts and introduces the RapidRead design principles. The first experiment compares five alternative checklist presentation styles. Four are drawn from the literature:

Table 1: Checklist settings vary based on task, pressure

Routine	Everyday (timeout)	Orderly, Predictable	Single focus / operation
Crisis	Emergent (code blue)	Chaotic, Uncertain	Concurrent focus / tasks

Table 2: Checklist usage patterns vary by time, linearity

Mandatory	Norms, Standards	Linear Use (Contiguous)	Long (Minutes)
Discretionary	Ad Hoc, Voluntary	Non-linear (Skip, skim)	Short (Seconds)

Standard Text [38], *Color Block* [6], *Pictographic* [7], and *Dynamic Focus* [37]. The fifth, *Structured Text*, modifies *Standard Text* to conform to an early, static version of RapidRead. These aids all support Advanced Cardiac Life Support (ACLS) crisis response. In this within-subjects study, medical participants (n=13) responded fastest with *Dynamic Focus* aids. Eye-tracking analysis showed the importance of clear visual navigation paths, anchors, and rapid scanning (see Figure 1). A second experiment compared Dynamic Focus aids to a new design that applied the RapidRead principles to the Dynamic aids. This revision further reduced performance variation. We discuss reasons for these benefits, reflect on performance and eye-tracking data, and suggest future work.

Checklist Setting Affects Usage Criteria and Patterns

To understand crisis checklist use, we observed over a dozen high-fidelity medical simulations and post-simulation participant debriefs. Clinical instructors ran these training at a medical simulation center with robot mannequins and a team of confederate doctors and nurses.

Anesthesia residents took turns playing the roles of team leader and backup. Other doctors, teachers, and researchers observed from behind a one-way mirror or through live video. Instructors designed simulated crises, typically lasting half an hour, where residents respond to unexpected and emergent events. In these simulations, residents had voluntary access to paper checklists in binder form, and later, digital checklists on tablets and large displays.

We expected doctors' checklist use to echo airline pilots', where one or two people iterate through a list of items verbally, using challenge-response [9] or cross-check. In aviation, there are consistent takeoff and landing scripts. Social protocol is scripted, and the team has a single focus. There are cases when medical checklist use is similarly linear and predictable. In pre-surgery time-outs, now typically mandatory, the entire medical team pauses to verbally review a fixed number of steps [26]. Another example of routine settings (Table 1) and mandatory use (Table 2) is the checklist for putting in central lines [30], where an individual checks through a consistent set of items in order.

We observed a large gap between checklist use in routine care and chaotic crisis response. Although residents were taught to use cognitive aids, not all did. Crisis and trauma care are non-linear and highly concurrent. Doctors mix usage styles: skimming, skipping sections, looking up information for rare procedures, or answering specific questions, such as how much Dantrolene to administer [16].

Medical checklists have additional challenges. Human bodies are complex and treatment methods are not as linear as checklists for engineered processes [12]. Teams are large, with a diversity of specialties. Interruptions are common [5,18], and checklist use is not always mandatory [13].

Rapid, chunkable reading is important for multiple reasons. In externally-paced tasks like driving and surgery, diversion from the primary task degrades routine monitoring performance (like steering) and slows reaction time to surprise crises [27,35]. Distraction and off-road gaze time correlates with more automobile accidents [15,19]. In aviation, slow, difficult-to-read checklists contributed to several accidents [10]. Furthermore longer secondary task times increase the chance of prospective memory errors [35].

Finally, the ability to rapidly acquire information from external resources increases people's usage [21,34]. This implies that users may implicitly invoke a cost model for discretionary aid use, informed by perceived benefit of knowledge versus perceived acquisition cost [26].

DESIGN PATTERNS FOR RAPIDREAD CHECKLISTS

Given the goal of creating crisis checklist aids that are fast to use, we now present design principles and patterns to accomplish this. These principles distill and extend strategies used in existing aids, principles derived from human perception and multitasking research, and insights from participatory design [37]. Some principles were briefly sketched in prior work [37]. These were refined and improved after experimentally analyzing their usage and effectiveness.

These techniques are designed to increase the speed of information search in procedure aids. We call designs that organize aids into chunks that fit in a multi-tasking cycle a *step-at-a-glance* user interface.

The RapidRead design concept combines three approaches:

1. Dynamically add detail around the current step while reducing it elsewhere with *dynamic focus;*
2. Express information concisely in a stereotyped format called *object-action language*; and
3. Map knowledge into graphically-defined *information patches* to increase speed of search.

Dynamic Focus Balances Simplicity and Complexity

We found, as prior work did, that in crises, doctors attention is a limited resource, and most gaze times are short (<10 s) [24]. To address the limited attention in medical trauma and crisis response, prior work has winnowed information on

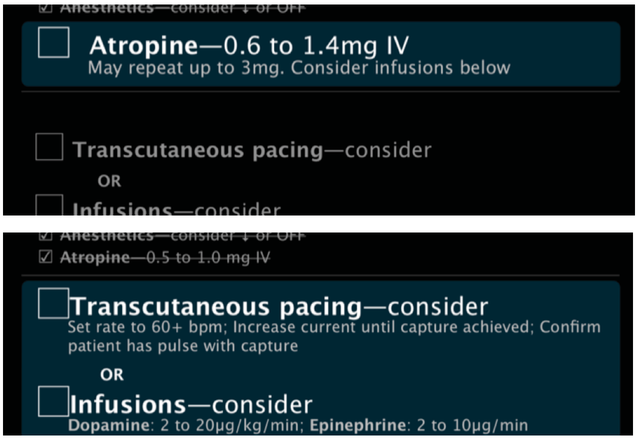

Figure 2: In this example of the Dynamic Focus technique, after the Atropine step is completed, the next step is given focus.

interactive displays to just the most important elements [25] [37]. During crises, we hypothesize that checklists can aid cognition by only showing information that is relevant to the current operating context, and minimizing or omitting less-related content.

To achieve this, we introduce Dynamic Focus, an extension of the focus+context visualization [4] that combines overview (context) and detail information (focus) with no occlusion. Dynamic Focus displays extend this approach with a situation-specific focus. For example, in car navigation, turn-by-turn directions often auto-update to show only the next turn, rather than the entire route. Drivers make fewer errors and lane deviations with auto-updating turn-by-turn directions than route overviews [15]. Consequently, guidelines suggest that "drivers should not be expected to process complex information to obtain the desired route, *i.e.*, the systems should not display a map with a highlighted route" and a limit of 15 seconds for task interactions [15].

Many cognitive aids partition information into sections, for example Signs, Treatment Protocol, and Differential Diagnosis. In a Dynamic Focus aid, typically one section is expanded; the others are collapsed. Within a block, there is a selective focus on the current step; future steps are de-emphasized and executed steps crossed out (see Figure 2).

Object-Action Language Provides Brevity & Structure

This pattern codifies a strategy developed in aviation. For example, the checklist for an MD-80 airliner emphasizes the airplane configuration for takeoff, landing, *etc*. [10]. The left lists the object; the right lists the action to be taken on it, usually the configuration state to be set. For example:

BRAKES ....SET
WINDSHIELD HEAT ....ON

This checklist language is compact, even terse. This compactness has at least four benefits: 1) more steps fit in a small space; 2) the checklist can be searched quickly because objects (left) and actions (right) are aligned; 3) the steps are quick to read because they have been reduced to a canonical form; and 4) people can verbally refer to elements using spatial language. The following example shows the application of RapidRead to medical checklists. The more usual checklist language:

Increase FiO_2 to 100%
Verify ischemia with 12 lead EKG if possible

is re-expressed as:

FiO_2 ↑100%
Ischemia Verify
Use 12-lead EKG.

We call this *object-action notation*.

Drug parameter sub-language. Drug dosages appear frequently in checklist statements. Misreading these statements is so consequential that it is necessary to have a canonical dose presentation. In this sublanguage, the drug name is given (even if it repeats object), followed by the dose and units (in square brackets if an interval), then additional instructions like 'IV' or 'max dosage'. For example:

Calcium chloride 1g IV
Epinephrine [2~10μg/min]

Machine Parameter sub-language. Generally, the machine name is the object, and the action relates to the parameter of the machine, either as Parameter = Value or Parameter: Action. For example:

Pacer Electrodes: Place on chest
Mode = Pacer
Current: Increase mA until capture

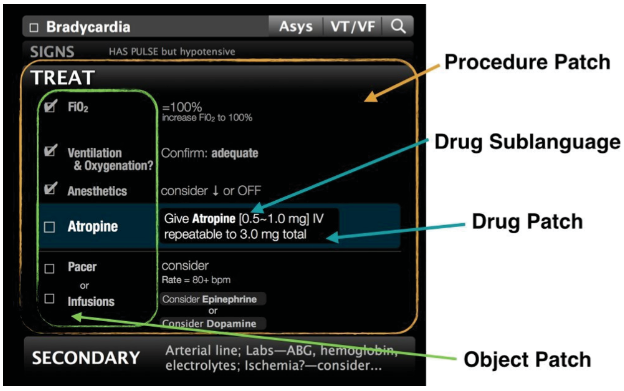

Figure 3: RapidRead aid principles: patches highlighted

Information Patches Aggregate Related Content

To support rapid, random access, RapidRead uses visual patches to focus information search to a small, quickly-recognizable region. RapidRead separates steps spatially, and information types typographically (see Figure 3).

Procedure blocks. Procedure blocks group a small number of steps (up to five). Blocks can be of several types including *signs, do immediately*, *treatment*, or *(differential) diagnosis*. Procedure blocks have a subtly colored background. This color cue both identifies the block type and defines the patch perceptually with a low spatial frequency region [32].

Drug patches. A gray background under the drug parameter specification creates another low spatial frequency region.

Object patches. With complex information, there are often multiple relevant groupings. Tufte's concept of *layering and separation* uses distinct visual variables—like color or alignment—to provide different types of information simultaneously [33]. We employ this to present objects as a group. For example, in Figure 3, "Objects" form a vertically aligned cluster. This helps people quickly locate objects by consistently placing them on the left and rendering them in bold. Other elements are rendered in lighter type.

EXPERIMENT 1: HOW DESIGN IMPACTS RESPONSE TIME

We chose to study aid design in a controlled laboratory setting gathering fine-grained data from many participant trials. The first experiment compared five different sets of checklists (Figure 4) in a within-subjects experiment on medical professionals. Four sets were drawn from the literature. We created the fifth set (*Structured Text*) by modifying the *Standard* aids to employ the object-action, information patch, drug patch, and object patch patterns.

This experiment asked participants to find information embedded in aids for Advanced Cardiac Life Support (ACLS) [28]. ACLS was chosen for its ubiquity and importance: U.S. medical school and advanced emergency medical technician (EMT) programs require ACLS coursework.

Method

To ensure sufficient understanding of aid terms and usage, the 13 participants comprised 2 ACLS trained EMTs and 11 medical doctors. Participants were compensated $40. The experiment compared five presentation styles representing diverse approaches to checklist design. These were chosen to include the most common aids used in studies and to span the design space of aids used in practice.

Standard Text. This set of aids has shown to be effective in high-fidelity medical simulation [38] (Figure 4a).

Structured Text. These aids build on *Standard Text*, but distill their presentation into an abridged format (Figure 4b).

Color Block. These aids use color and visual design to delineate different conceptual chunks [6] (Figure 4c).

Pictographic. These aids have similar content and wording to *Color Block*, but have drastically differing visual presentation. They use graphical images for each step of the checklist in addition to textual information as a way to provide visual landmarks [7] (Figure 4d).

Dynamic Focus. These aids also draw their content from *Color Block*. They change display, showing more detail for the current step than other steps [37] (Figure 4e).

All styles were presented on the same display at the same resolution density. For example, one page of *Standard Text* used the same number of pixels as one page of *Structured Text*, and half the pixels of a two-page *Pictographic* aid.

Hypotheses

This experiment evaluated three hypotheses:

H1 Participants are fastest with *Dynamic Focus* because it reduces the amount of information displayed at one time. The static aid styles lack dynamic focus.

H2 *Structured Text* and *Color Block* outperform *Standard Text* due to increased structure

H3 *Pictographic* will have high variance in performance, reflecting the differences in benefit of visual icons for different tasks.

Procedure

In a within-subjects Latin square design, each participant was timed on answering the same 15 information look up questions on each of five distinct styles of medical aids, totaling 75 questions. Some questions were simple lookup; others required some inference. These questions were modeled on information needs observed in simulated crisis response and instructor commentary on common mistakes. For each type we present one example:

Drug Parameter: What is the correct dose for atropine?

Procedure Parameter: What is the appropriate ventilation rate during CPR?

Drug Selection: What drug and dose would you use to treat a calcium channel blocker overdose?

To ensure that responses were not memorized, question answers were altered. For example, instead of putting down the correct Epinephrine drug dosage of 1mg, we put down similar numbers like 2mg or 3mg. Questions spanned 4 ACLS topics: Pulseless Electrical Activity (4), Supraventricular Tachycardia (3), VT/VF (4), and Bradycardia (4). A full list of questions is available online [39].

Sequence. After a short pre-study questionnaire to record demographic information (occupation and years of experience) participants were given two example questions as a brief training. Participants were seated in a chair at a fixed distance of approximately 2' from a 22" monitor with a

a) *Standard Text*, b) *Structured Text* c) *Color Block* d) *Pictographic* e) *Dynamic Focus*

Figure 4: To find effective checklist design strategies, we compared five diverse styles; the Asystole aid for each is shown here.

1680×1050 pixel resolution. Participants paced themselves using a keyboard. After reading a question, they pressed the spacebar to show the aid. Once they found the answer, they said the answer aloud, and pressed the spacebar again to advance to the next question. The experiment measured response time for answers as the interval between spacebar presses. Each session was videotaped, and a SMI RED eye-tracker captured participants' eye movements. This eye-tracker requires no restraint or equipment to be worn, and is accurate to approximately .5~1 degree of arc.

Measures

The primary measure was the time participants took to locate the requested piece of information within the aid. Response times are compared using a fixed-effects linear model that uses participant, question, and condition.

Second, we compared the fraction of responses that exceed task-relevant thresholds–10 and 20 seconds [24]. Third, we compare variation in response times using the coefficient of variation. This metric is useful as it scales the standard deviation by the mean, allowing easy comparison between conditions. Threshold and variation analyses are important for paced tasks like crisis response and driving to measure the likelihood that an information task fits into a safe cycle time for diverting attention from the primary task [31].

Results

Dynamic Focus response times were fastest: 41% faster (avg. 5.7s) than *Standard Text* (avg. 9.6s) (Table 3). This difference was statistically significant (β=-4.3, t(796)= -6.8, p<.001). *Color Block* was 16% faster (β=-1.5, t(796) = -2.4, p<.05) than *Standard Text*. Average response times for the other aids were statistically indistinguishable from *Standard Text*. Since long answer times are particularly dangerous, Tables 3 also reports the percent of trials exceeding 10 or 20 seconds; the percent beyond 20s ranged from 0% for the *Dynamic* aid to 34% for the *Standard Text* aid.

Participants averaged about 2 incorrect answers out of 75. Response times were log-normally distributed: for the log-transformed distribution, skewness was 0.5 and the excess kurtosis was 0.1, both close to the expected value of 0 for a normal distribution. Consequently, all statistical analyses that depend on data normality use log-transformed data.

	Mean	**>10 s**	**>20 s**
	(s)	(%)	(%)
Dynamic Focus	5.7 ± 50	10	0.0
Color Block	8.1 ± 60	22	4.3
Pictographic	9.0 ± 59	30	6.8
Structured Text	9.1 ± 70	31	7.3
Standard Text	9.6 ± 69	34	7.3
Mean	8.3 ± 65	25	5.1

Table 3 – Answer time means (sec) by style. The symbol ± indicates coefficient of variation, defined as the standard deviation divided by the mean. Also see Figure 5.

Discussion

Hypothesis H1, part of H2, and H3 were confirmed: *Dynamic Focus* aids were fastest, and *Color Block* aids outperformed *Standard* aids. The *Pictographic* aid had high variance in comparison to the Standard Text aids (see Figure 6 left). However, H2's claim that *Structured Text* aids would be faster than *Standard Text* aids was not substantiated.

Why were the Dynamic aids so much faster?

Which attributes correlated with faster search? Eye traces highlight three effective strategies. Successful designs reduced searchers' eye movements by laying out a search path, quickly guiding them to a salient patch, or reducing the effort of digesting information once found.

Consistent structure

Information blocks helped participants find information faster. By containing related information, blocks allowed participants to quickly dismiss or focus on a patch. In Figure 7 far-left, the participant quickly dismissed 3 blocks before locking onto the treatment box.

Consistent with information foraging theory [29], most eye traces began with a broad scanning phase to locate the right patch, followed by focused consumption of that patch's information. Figure 7 middle shows how a consistent presentation using the object-action language and object patch format sped participants' scanning. Participants' eyes followed the object column until they found the drug name, then moved to the action column to read the dosage information. By contrast, the standard text aids have less visual structure, requiring participants to scan all of the text.

Only the necessary information

Reducing the amount of information makes choices easier. In static layouts, there is a tradeoff between the amount of information and search complexity. Dynamically expanding step-relevant information and minimizing irrelevant information sped participants' search (see Figure 7 far-right).

Troubleshooting Cognitive Aids

This study also illuminated design flaws and opportunities for improvement in all of the aids styles. By analyzing questions with highly differential response times across the designs, we could focus on places where information design had a significant impact. In Figure 6, points along the y=x line indicate questions where response times for an aid were

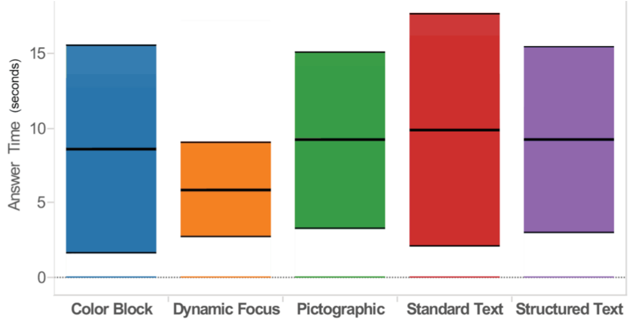

Figure 5 - Answer time means (sec) by style ± 1 stdev bars

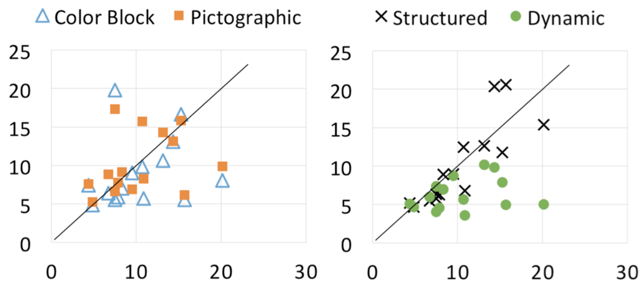

Figure 6: A comparison of mean answer times (seconds) for each question. Time for *Standard Text* aid is on x-axis, y-axis is time for indicated aid style. Points below the line y=x indicate the aid was faster than *Standard*. *Dynamic* (right) was fastest, but each style performed well on some questions.

equivalent to the *Standard* Aid. The top-left or bottom-right quadrants indicate questions where a design is performs much better or much worse than the *Standard* aids. Here are three especially salient design issues identified with response time data and understood using the eye-tracking data. These issues highlight useful design patterns, or anti-patterns, that can be used to improve aid design.

Visual paths can lead to the answer … or a dead end

The first issue was failure to group information for a single procedure within the same patch. This resulted in participants spending long period of time looking in the wrong place on the aid. For the question, "What is the appropriate ventilation rate during CPR for a patient in PEA?", *Structured Text* had average response time of 6.1s, with 3.0s sd. *Color Block* had many more slow responses, with an average of 15.9s and sd 13.2s. What led to this large difference?

The heat maps show that because the *Structured Text* aids put all CPR related information in one procedure block, the participants indeed focused there (see Figure 8a). In contrast, participants using *Color Block* spent most of their time looking in a block with CPR information, though the answer was elsewhere (see Figure 8b).

Lost without an anchor

The second issue was that key information in block titles were visually de-accentuated, which resulted in participants repeatedly missing the information (see Figure 8c). For the question, "Patient is in unstable SVT. Should shock be synchronized or unsynchronized for a narrow complex regular rhythm?", the Dynamic Aid had average response time of 8.9s and sd of 3.2s. The Structured Text aid had average 18.7s and sd 6.5s.

In the Structured Text aid, the key information—that the shock should be 'unsynchronized'—is located in a small font, all caps, and as a block title. Many people missed this when scanning larger bold items just below (see Figure 8c). This violates RapidRead's goal of placing all actionable information on the right of a relevant object-action phrase. In *Dynamic Focus*, the line with 'unsynch' is highlighted, has bold key terms, and mixes case.

Support rapid scanning

A third issue was when machine parameter setting were repeated or split across blocks. They created visual distractors and participants often wasted time making sure answers were consistent before reporting them. For the question, "How many Joules should you shock at?", the *Dynamic Focus* had average response time of 4.8s and sd of 1.6s. The Standard Text aid had average 18.7s and sd 13.7s.

The heat map images in Figures 8d and 8e show a large contrast in the behavior of participants across the two conditions. Participants were efficient when using the Dynamic aid. They first hit the title 'Defibrillate' and looked to the right to see the Joules. In contrast, with the Standard aid, participants looked in four separate areas because machine parameters were spread over three different sections. The largest distractor was the middle right, where a block titled *Defibrillator* did not contain the shock setting. The second distractor was the top-right box titled *During CPR*. Actual content was located on the left side. Repeated information seemed to hurt rather than help, as participants sometimes cross-checked to verify their answer was consistent.

This analysis drove a new design pattern for the RapidRead principles, the machine parameter sub-language.

EXPERIMENT 2: STRUCTURE REDUCES VARIANCE

Based on the results of Experiment 1, we updated the

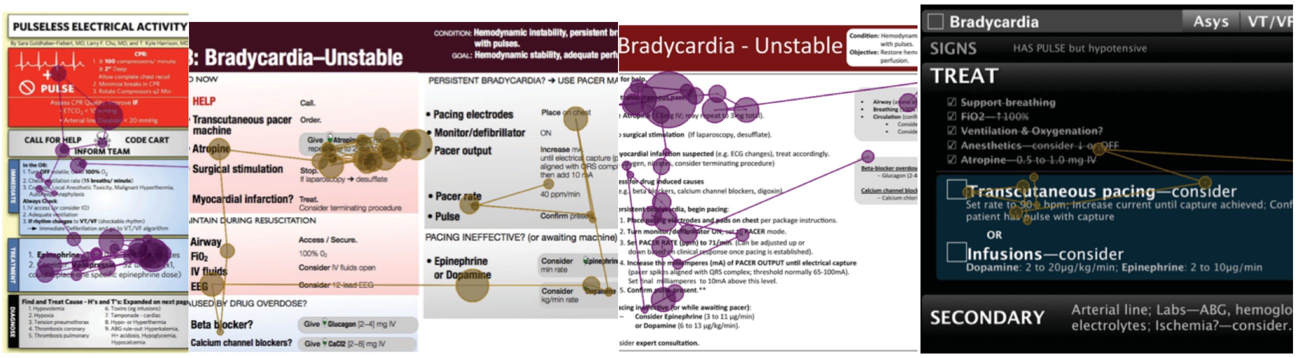

Figure 7: (Far-Left) *Color Block* paths suggest visual chunking helps
(Middle) Gaze path analysis compares *Structured Text* alignment (left) to relatively unstructured *Standard Text* (right)
(Far-Right) *Dynamic Focus* demonstrates fast convergence

RapidRead principles. We added the machine parameter sub-language, and more systematically consolidated information patches. Would applying the revised guidelines to one of the aid styles improve performance? Our base was the *Dynamic Focus* aid because it best instantiated the RapidRead principles. We created an updated version called *Rapid Dynamic* that incorporated object and drug patches, as well as the machine and drug parameter sub-language.

Method

Eleven of the thirteen participants from the first experiment returned for a follow-up study. For taking part in the second experiment, participants were compensated $40. The new *Rapid Dynamic* design was created to compare to the *Dynamic*. Presentation format stayed the same. Participants first repeated seven of the fifteen original questions chosen for high variance and similar overall average to the full set. They then answered these questions again for both the original *Dynamic* design and the *Rapid Dynamic* redesign. Question order was Latin square counter-balanced as in experiment 1 and answers were changed for each presentation.

Results

We focus on the results between *Dynamic* and *Rapid Dynamic* for this paper. *Dynamic* averaged 3.7s with a sd of 4.2 and a coefficient of variance of 0.57. *Rapid Dynamic* averaged 3.1s with a sd of 0.95 and a coefficient of variance of 0.29. The difference between means was not significant, but *Rapid Dynamic* had significantly less variance ($F(48,48)=3.4$, $p < 0.001$). On average, Participants gave less than 1 incorrect answer out of 35+24 questions.

Discussion

For paced task environments like crisis medicine, reducing variance can be even more important than increasing average speed. The difference between 8 and 10 seconds may not be relevant, but if a quick information lookup takes 30 or 60 seconds even one time it can be disastrous. By increasing the consistency of the design our RapidRead techniques try to reduce those outliers and make aids more dependable. The eye traces show the same behavior changes between the *Dynamic* and *Rapid Dynamic* aids as Figure 7 shows between the *Standard Text* and *Structured Text* aids.

CONCLUSIONS AND FUTURE WORK

This paper introduced the RapidRead approach for designing cognitive aids. Two studies compared search times and eye traces for six presentation styles, finding that *Dynamic Focus* aids sped information search. Eye-trace analysis suggested the benefit of object-action language and information patches. This work is one of the first to empirically study how design impacts checklist performance.

Readers should keep in mind three important considerations in applying these results. First, participants were solitary, seated, and answered isolated questions about a single aid. Crises generally involve teamwork, information needs are embedded in the larger tasks, and checklist use is discretionary and bursty. Second, future work should explore with larger populations how expertise affects performance. Third, these studies analyzed a small number of representative design styles. Each represents many design small design decisions about exact layout, typography, and information density. A predictive model that explicitly incorporates these variables remains future work.

These studies illustrate how analyzing eye traces can help build predictive models of response time variation. We see this as a promising approach for evaluating time-critical information systems. More broadly, we seek a predictive theory for estimating how visual design affects performance. Future work might fruitfully explore how the RapidRead pattern can apply to other domains for other time-critical domains and for information resources more generally. As the Web has made it tractable for much of the world's information to be readily available and dynamic, there are many exciting opportunities for adaptive presentation strategies.

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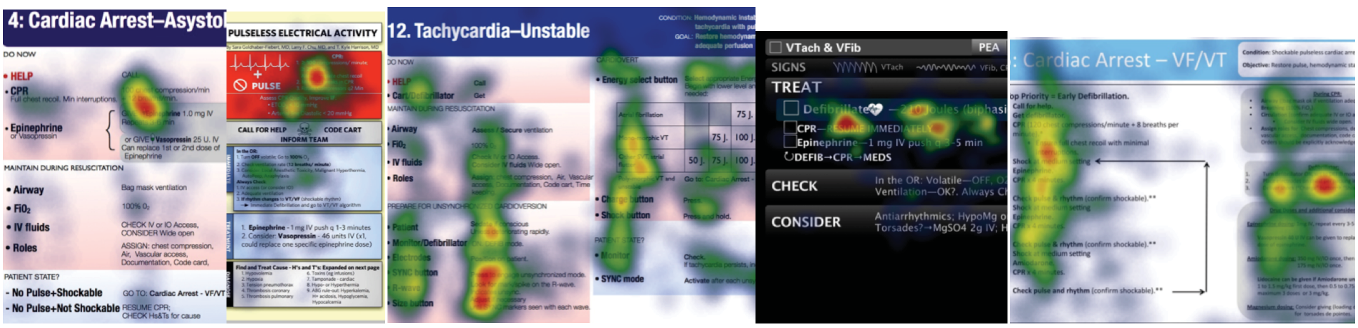
REFERENCES

1. Arriaga, A.F. et al. Simulation-based trial of surgical-crisis checklists. *N Engl J Med*., (2013).
2. Boorman, D. Safety benefits of electronic checklists: An analysis of commercial transport accidents. *Proceedings 11th Intl. Symposium on Aviation Psychology*, (2001).
3. Burian, B.K., Barshi, I., and Dismukes, K. *The Challenge of Aviation Emergency and Abnormal Situations*. Moffett



(a) *Structured Text* (b) *Color Block* (c) *Structured Text* (d) *Dynamic Focus* (e) *Standard Text*

Figure 8: Troubleshooting long latency. Heat-maps show where participants focused their gaze on each aid.

Field, California, 2005.

4. Card, S.K., Mackinlay, J.D., and Shneiderman, B. *Readings in information visualization: using vision to think*. Morgan Kaufmann Publishers Inc., San Francisco, 1999.
5. Chisholm, C.D., Collison, E.K., Nelson, D.R., and Cordell, W.H. Emergency Department Workplace Interruptions: Are Emergency Physicians "Interrupt-driven" and "Multitasking"? *Academic Emergency Medicine*, (2000).
6. Chu, L. and Fuller, A. *Appendix C: Crisis Management Cognitive Aids in Manual of Clinical Anesthesia*. Lippincott, 2011.
7. Chu, L. and Harrison, T.K. *ACLS Emergency Aids*. 2012.
8. Coiera, E.W., Tombs, V.J., and Clutton-Brock, T.H. Attentional overload as a fundamental cause of human error in monitoring. (1996).
9. Degani, A. and Wiener, E.L. *Human Factors of Flight-Deck Checklists : The Normal Checklist*. Ames Research Center, 1990.
10. Degani, A. *On the typography of flight-deck documentation*. NASA-Ames Research Center, Moffett Field, CA, 1992.
11. Dekker, S. *Patient Safety: A Human Factors Approach*. CRC Press, Boca Raton, FL, 2011.
12. Gaba, D.M., Fish, K.J., and Howard, S.K. *Crisis Management in Anesthesiology*. Churchill Livingstone, New York, 1994.
13. Gawande, A. *The Checklist Manifesto: How to Get Things Right*. Metropolitan Books, NY, 2009.
14. Gawande, A. Project Check. 2013. http://www.projectcheck.org/checklist-for-checklists.html.
15. Green, P. The 15-second rule for driver information systems. *Proc of the ITS America*, (1999).
16. Harrison, T.K., Manser, T., Howard, S.K., and Gaba, D.M. Use of Cognitive Aids in a Simulated Anesthetic Crisis. *Anesthesia & Analgesia*, (2006).
17. Haynes, A.B. et al. A surgical safety checklist to reduce morbidity and mortality in a global population. *N Engl J Med.*, (2009).
18. Healey, A.N., Sevdalis, N., and Vincent, C.A. Measuring intra-operative interference from distraction and interruption observed in the operating theatre. *Ergonomics*, (2006).
19. Horrey, W. and Wickens, C. In-vehicle glance duration: Distributions, tails and a model of crash risk. *Journal of the Transportation Research Board*, (2007).
20. James, J.T. A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care. *Journal of Patient Safety*, (2013).
21. Kalnikaité, V. and Whittaker, S. Software or wetware?: discovering when and why people use digital prosthetic memory. *Proc. of the SIGCHI conference on Human Factors in Computing Systems*, (2007).
22. Kirsh, D. Metacognition, distributed cognition and visual design. *Cognition, education, and communication technology*, (2005).
23. Kohn, L.T., Corrigan, J., and Donaldson, M.S. *To Err is Human: Building a Safer Health System*. Washington, D.C., 2000.
24. Kusunoki, D.S., Sarcevic, A., Zhang, Z., and Burd, R.S. Understanding visual attention of teams in dynamic medical settings through vital signs monitor use. *Proceedings of the 2013 conference on Computer supported cooperative work - CSCW '13*, ACM Press (2013).
25. Kusunoki, D.S. et al. Balancing design tensions: Iterative display design to support ad hoc and interdisciplinary medical teamwork. *Proc. of the ACM SIGCHI Conference on Human Factors in Computing Systems*, (2014).
26. Makary, M.A. et al. Operating room briefings: working on the same page. *Joint Commission Journal on Quality and Patient Safety*, (2006).
27. Monk, C. a, Trafton, J.G., and Boehm-Davis, D. a. The effect of interruption duration and demand on resuming suspended goals. *Journal of Experimental Psychology*, (2008).
28. Neumar, R.W. et al. Part 8: adult advanced cardiovascular life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*, (2010).
29. Pirolli, P. *Information Foraging Theory: Adaptive Interaction with Information*. Oxford University Press, 2007.
30. Pronovost, P. et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med.*, (2006).
31. Salvucci, D.D. and Taatgen, N.A. *The Multitasking Mind (Cognitive Models and Architectures)*. Oxford University Press, USA, 2010.
32. Tovée, M.J. *An Introduction to the Visual System*. Cambridge University Press, 2008.
33. Tufte, E.R. *Envisioning Information*. Graphics Press, Cheshire, CT, USA, 1990.
34. Verdaasdonk, E.G.G., Stassen, L.P.S., Widhiasmara, P.P., and Dankelman, J. Requirements for the design and implementation of checklists for surgical processes. *Surgical endoscopy*, (2009).
35. Wickens, C.D. and McCarley, J.S. *Applied Attention Theory*. CRC Press, 2007.
36. Winters, B.D. et al. Clinical review: checklists - translating evidence into practice. *Critical Care*, (2009).
37. Wu, L. et al. *Supporting crisis response with dynamic procedure aids*. 2013.
38. Ziewacz, J.E. et al. Crisis checklists for the operating room: development and pilot testing. *J. of the American College of Surgeons*, (2011).
39. Questions: https://gist.github.com/icogaid/6604919.
40. *Human Performance Considerations in the Use and Design of Aircraft Checklists*. U.S. Department of Transportation, Federal Aviation Administration, Assistant Administrator for System Safety, Office of Safety Services, Safety Analysis Division, 1995.