EFLM Paper

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Efficiency, efficacy and subjective user satisfaction of alternative laboratory report formats. An investigation on behalf of the Working Group for Postanalytical Phase (WG-POST), of the European Federation of Clinical Chemistry and Laboratory Medicine (EFLM)

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Abstract

Objectives: Although laboratory result presentation may lead to information overload and subsequent missed or delayed diagnosis, little has been done in the past to improve this post-analytical issue. We aimed to investigate the efficiency, efficacy and user satisfaction of alternative report formats.

Methods: We redesigned cumulative (sparkline format) and single reports (improved tabular and z-log format) and tested these on 46 physicians, nurses and medical students in comparison to the classical tabular formats, by asking standardized questions on general items on the reports as well as on suspected diagnosis and follow-up treatment or diagnostics.

Results: Efficacy remained at a very high level both in the new formats as well as in the classical formats. We found no significant difference in any of the groups. Efficiency improved in all groups when using the sparkline

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cumulative format and marginally when showing the improved tabular format. When asking medical questions, efficiency and efficacy remained similar between report formats and groups. All alternative reports were subjectively more attractive to the majority of participants.
Conclusions: Showing cumulative reports as a graphical display led to faster detection of general information on the report with the same level of correctness. Considering the familiarity bias of the classical single report formats, the borderline-significant improvement of the alternative tabular format and the non-inferiority of the z-log format, suggests that single reports might benefit from some improvements derived from basic information design.

Keywords: format; information design; laboratory report; postanalyticsz.

Introduction

Improved presentation of laboratory information can facilitate faster interpretation and more accurate diagnoses and treatment [1]. This simple yet so important finding of Wright et al. should be common sense, considering how information is delivered in our daily life. Traffic signs, street names, danger warnings, web design, operating systems of all our electronic devices, etc. All of these use the principles of information design in order to increase effectiveness and user acceptance of information, referred to as user centered design (UCD) [2]. However, in medical care the application of a user centered design to foster information processing is scarce. This applies for many medical disciplines, including laboratory medicine.

Laboratory reports are usually issued in a tabular format, which has intrinsic benefits for some situations (e.g. finding exact values), but surely not in all. These reports are partially designed by the individual laboratory in cooperation with the IT company providing the electronic Health Record – (EHR), or the Laboratory Information system (LIS). In reality, the report frontend is mostly being designed without the input of users, except in situations like in third-party intensive care unit software solutions, in which user requests from clinicians are usually taken into account. However, in these cases too, the laboratory is merely providing numerical results, without having any control over their presentation. Hence, there is absolutely no standardization in how test results are or should be presented. Unfortunately, standardization of information delivery is one of the key components when it comes to efficient and effective information processing. Cognitive effort that is directed towards decoding the encoded information using different layouts can be drastically reduced through automated processing (by relying on schemata in long-term memory) and directed towards the actual job – interpreting the reported results.

Thus, some recommendations and proposals have been issued in the past decades, but mostly for certain laboratory sub-disciplines, often with contradicting statements focusing mainly on the content of the report rather than its format [3–6]. Even the EN-ISO 15189 regulation, with all its detailed information on how to improve laboratory quality and evaluate the effectiveness of laboratory management, does not reflect on the report format or its impact on patient care [7].

The report, as presented by most laboratories, does hardly reflect the strenuous efforts of laboratories in providing high quality analytics in the shortest amount of time possible, with the lowest error rates throughout medical care [8]. It does not tap the full potential of neither modern information technology solutions nor automated processing for data aggregation. It is like serving Haute Cuisine in a bucket.

We therefore redesigned laboratory reports for single and cumulative results and tested them on health care volunteers, aiming to investigate their efficiency, the efficacy and the user satisfaction in comparison to a standard tabular format.

As the terms efficacy, efficiency and effectiveness differ when applied to management or health care, we used the definition of Buches et al. [9]. They state that efficacy, in the health care sector, is the capacity for beneficial change (more correct answers) of a given intervention (alternative laboratory reports) under controlled conditions, while effectiveness is the same under normal clinical conditions (observational studies). Efficiency is defined as achieving higher levels of performance (finding an answer within the report) relative to the inputs (time) consumed. Hence, efficacy was calculated as the number of correct answers divided by total answers given and efficiency was the time to answer, measured in seconds.

Materials and methods

Based on the findings of our recent review on laboratory result reporting [10], we designed three alternative report formats for single and cumulative laboratory results in collaboration with a research group (research group for accounting, controlling and financial management, school of business & management, University of Applied Sciences Upper Austria, in Steyr, Austria), focusing on improving information design (Supplemental Figures 3–5). Single reports were either presented as a table with optimized formatting including information to depict trends in comparison to the preceding laboratory test results (“improved table format”;Supplemental Figure 3), or as a deviation graph, showing results as z-log values within a ± 2 SD-scale (“z-log format”; Supplemental Figure 4). The alternative cumulative report was depicted as modified sparkline diagram (“sparkline format”; Supplemental Figure 5).

We populated all of these reports with fictional data. To investigate the medical efficacy of single report formats, we used data reflecting patients with either iron deficiency anemia or with β-thalassemia.

As reference comparison, participants were shown "classical" tabular formats in which results outside the reference range (RR) were flagged with either "+", "++", "+++", "-" , "–" , or "—" , but without any formatting, either as single or as cumulative format (Supplemental Figures 1 and 2).

Subsequently, we defined standardized questions for each report format, regarding general information presented on the respective report, as well as medical questions on diagnosis and follow-up diagnostics (Table 1).

In collaboration with the medical and nursing directors as well as the head of the medical studies course management, we invited physicians and nurses from the University Hospital Salzburg to participate in this study. To minimize bias from being too familiar to the current "classical" tabular formats in daily clinical practice, we additionally invited medical students from the affiliated Paracelsus Private Medical University (PMU) in their second year of education. Due to the COVID19 pandemic neither personal contact nor the use of eye tracking solutions were allowed. Therefore, all volunteers were interrogated via an online streaming service (MS Teams, Microsoft, WA, USA). Questions regarding medical diagnosis and treatment decisions were presented to physicians and medical students only. Questions were randomized in a way that asking the same participant identical questions on different formats was prevented, while providing the same number of classical and alternative formats to each participant. The time to answer (efficiency) and the correctness of the participants' answers (efficacy) were recorded. The correctness of their medical answers were evaluated and, according to the number of correct details (e.g. anemia, thrombocytopenia, impaired kidney function, etc.), grouped into incorrect and 20%, 40%, 60%, 80% and 100% correct, respectively.

Additionally, participants were asked to provide some information on their level of expertise as well as an opinion on their personal preference, on the readability of the presented report formats (user satisfaction) and suggestions for improvements. Readability was assessed by asking to provide a rating (1/very bad to 5/very good) to the questions "How would you rate the usability of the report?" and "How easy was it to interpret the report?".

Data from these interrogations were anonymized and evaluated with the MS Excel software (Microsoft, WA, USA). For statistical comparison of general questions, we applied unpaired t-tests for evaluation of efficiency of cumulative reports. To test for normal distribution and the subsequent decision whether to use a parametric or non-parametric test, a Kolmogorov-Smirnov's test was performed. A Fisher´s exact test was applied to test for efficacy of cumulative reports. Single reports were evaluated using the Kruskal-Wallis' test. To test for differences in answers to medical questions, we applied a

Table 1: Standardized questions.

Type of report		Question	Who is asked		
Single	Cumulative		Clinicians	Students	Nurses
		General questions			
	●	How high was the XXX value two days ago?	●	●	●
	●	How did the XXX value change from three days ago to today?	●	●	●
	●	Did the XXX value improve, worsen or remained unchanged?	●	●	●
	●	At what day was the XXX value the highest and how high was it?	●	●	●
●		Which parameters deviate the most from their reference value?	●	●	●
●	●	Is there any diagnosis you could state upon this report?	●		
●	●	Would you know which further medical actions to take upon reviewing this report? (Additional lab testing, referral, follow-up diagnostic or treatment etc.)	●		
●	●	When was the patient born?	●	●	●
●	●	What was the clinical question for ordering this report?	●	●	
●	●	From which date and time is this report?	●	●	●
●	●	What is the patients name?	●	●	●
●	●	Which is the reference range for XXX?	●	●	●
●	●	What is the upper reference limit for XXX?	●	●	●
	●	What is the meaning of green points?	●	●	●
● (only z-log)		What do the numbers under "deviation from target value" mean?	●	●	●
		Medical questions			
●	●	Would you know which further medical actions to take upon reviewing this report? (Additional lab testing, referral, follow-up diagnostic or treatment etc.)	●		
		User satisfaction questions			
●	●	Which of the presented formats do you personally favor?	●	●	●
●	●	Do you have any suggestions for improvement?	●	●	●

Table 2: Demographics and subjective favoring of report formats.

Demographic information	**Physicians**		**Medical students**		**Nurses**		
Participants, n (% female)	17 (29%)[a]		17 (65%)		12 (50%)		
Number of lab reports read per day, mean (min–max)	74 (5–250)				21 (5–40)		
Years of experience, mean (min–max)	18.9 (3–33)				13.3 (5.5–25)		
Cumulative report formats	**Fe-anemia**	**β-Thal**	**Fe-anemia**	**β-Thal**	**Fe-anemia**	**β-Thal**	**Mean**
Classical cumulative tabular format compared to sparkline format							
– Readability of the classical cumulative tabular format, mean	2.6		2.9		3.0		2.8
– Readability of the sparkline format, mean	3.9		4.7		4.0		4.2
– In favor of the sparkline format	82%		88%		75%		82%
Single report format	**Fe-anemia**	**β-Thal**	**Fe-anemia**	**β-Thal**	**Fe-anemia**	**β-Thal**	**Mean**
Classical tabular format compared to improved tabular format							
– Readability of the classical tabular format, mean	2.6	3.0	2.5	3.0	2.2	2.3	2.6
– Readability of the improved tabular format, mean	4.1	3.9	4.2	4.3	4.4	4.3	4.2
– In favor of the improved tabular format	57%	40%	27%	50%	100%	43%	55%
Classical tabular format compared to z-log format							
– Readability of the z-log format, mean	4.1	4.0	4.6	4.3	3.8	4.3	4.2
– In favor of the z-log format	43%	60%	73%	50%	0%	57%	45%

Readability was assessed by asking the questions "How would you rate the usability of the report?" and "How easy was it to interpret the report?", providing a scale from 1/very bad to 5/very good. Fe-anemia, iron deficiency anemia; β-Thal, β-thalassemia. [a]Recruited physicians were from the following medical disciplines: surgery (n=3), cardiac surgery (n=1), pediatric surgery (n=1), oncology (n=1), nephrology (n=1), cardiology (n=1) anesthesiology (n=1), psychiatry (n=1), geriatry (n=2), pediatrics (n=2), general practitioner (n=2) medical intern (n=1).

Mann-Whitney's U test. A p-value<0.05 was regarded as significant difference between groups. All statistical analyses were performed using the GraphPad Prism Software v9 (GraphPad Software, CA, USA).

Results

We were able to recruit 46 volunteers to participate in this study (Table 2).

Efficacy

Overall, the efficacy of sparkline and improved tabular formats showed no significant differences, compared to the matching classical tabular reports for both general and medical questions. These overall results, as well as the grouped sub-analyses of physicians, nurses and students is shown in (Table 3).

Efficiency

All groups needed significantly less time (improved efficiency) to provide an answer to the standardized questions when answering to the general questions on the sparkline report, compared to the associated classical tabular format (Figure 1). The improved tabular format, however, showed only borderline significant (p=0.057) improvement in overall efficiency when asked general questions and no difference when asked medical questions (Figure 2). The z-log format showed no differences in efficiency.

User satisfaction

When asked about the readability of the shown formats and whether the classical tabular or the alternative reports (improved tabular, sparkline or z-log) were subjectively more attractive, the majority of participants preferred the alternative versions, regardless of the participant´s medical occupation (Table 2).

Suggestions on improvement

Answers to the question on further improvement possibilities are shown in (Supplemental Table 1). Most frequently, participants suggested to add or adapt arrows, to additionally add color to results outside the RR and to add dates to preceding results.

Table 3: Efficacy (correctness of answers) of re-formatted laboratory reports.

Questions	Report formats		Overall %	Overall Δ	Overall p	Overall n	Physicians %	Physicians Δ	Physicians p	Physicians n	Medical students %	Medical students Δ	Medical students p	Medical students n	Nurses %	Nurses Δ	Nurses p	Nurses n
General	Classical cumulative tabular report format		90%			184	85%			68	91%			68	94%			48
	Sparkline report format		90%	0%	1	184	88%	3%	0.801	68	90%	−1%	1	68	92%	−2%	1	48
	Classical single tabular report format		95%			75	97%			26	90%			29	100%			20
	Improved single tabular format		96%	1%	1	75	95%	−2%	1	26	94%	5%	1	29	95%	−6%	1	20
	z-log format		92%	−3%	1	80	89%	−8%	1	33	93%	3%	1	27	100%	0%	1	20
Medical	Classical tabular cumulative report format		22%			34	36%			17	7%			17				
	Sparkline report format		27%	5%	0.961	34	39%	2%	0.935	17	15%	8%	0.929	17				
	Classical single tabular report format	Fe-Deficiency	66%			14	92%			5	40%			9				
		β-Thalassemia	28%			11	55%			8	0%			3				
	Improved single tabular format	Fe-Deficiency	57%	−9%	0.774	11	70%	−22%	1	4	43%	3%	1	7				
		β-Thalassemia	32%	4%	0.855	10	52%	−3%	0.336	5	12%	12%	1	5				
	z-log format	Fe-Deficiency	50%	−16%	0.923	11	68%	−24%	1	5	31%	−9%	0.673	6				
		β-Thalassemia	34%	7%	0.652	11	69%	14%	0.445	7	0%	0%	0.595	4				

The percent value represents the correctness of answers (efficacy); the delta column represents the difference between answers to the respective reference format, where "p" is the significance level of this difference; n, number of answers.

Discussion

In this study, we found that by reformatting laboratory reports the efficiency can be improved in finding general information as well as trends in cumulative reports and with a non-significant tendency also in single reports while maintaining a high efficacy. User satisfaction increased in all of the reformatted reports, regardless of the participant´s medical occupation.

The variety of medical information formatting may span from 'clear as a traffic sign' to 'confusing as a *Where's-Waldo* search image'. As the effort in improving medical data presentation varies from hospital to hospital, we have to consider that in health care, unintuitive and confusing diagnostic data presentation may potentially cause information overload, missed or delayed diagnosis and subsequently to patient harm [11–14]. Despite this fact, too little has been done to apply simple information design principles on medical data, including laboratory test results.

The majority of medical decision-making is based on laboratory results and yet their presentation has not changed since … well, ever, it seems. Laboratory reports are traditionally presented in a tabular format, which was the easiest way at a time prior to the digital revolution. Over 40 years ago, Alan Bold stated that "*An unattractive, uninformative, or confusing report may fail to do justice to an excellent analytical service. Unfortunately, relatively little effort has been expended on achieving the best possible report, and individual enthusiasm and initiative has led to widely diverse practices in reporting. There is an urgent need for standardization of report formats*" [15]. However, even with the emerging digitalization of laboratories, the tabular formats were often merely adopted, instead of taking advantage of the new possibilities. Therefore, following up a recent review of ours, we aimed to test the theory that alternative report formats, generate improved medical outcome [10]. We developed reformatted reports for single and cumulative results, populated these with fictional data and presented them to physicians, nurses and medical students. Using standardized questions, we calculated the efficacy (correctness of the given answer) and efficiency (time to answer) of the reports. Additionally, we asked for the subjective preferences (user satisfaction). This study does not claim to cover all possible results report presentations, but merely aims to identify certain benefits from alternative report formats. In a routine setting, it has to be acknowledged that there is no "one-format-fits-all" solution for every analytical result. For example, "normal", "negative" or "positive" as a result may have different meaning and may trigger different medical action, depending on the analyte in question.

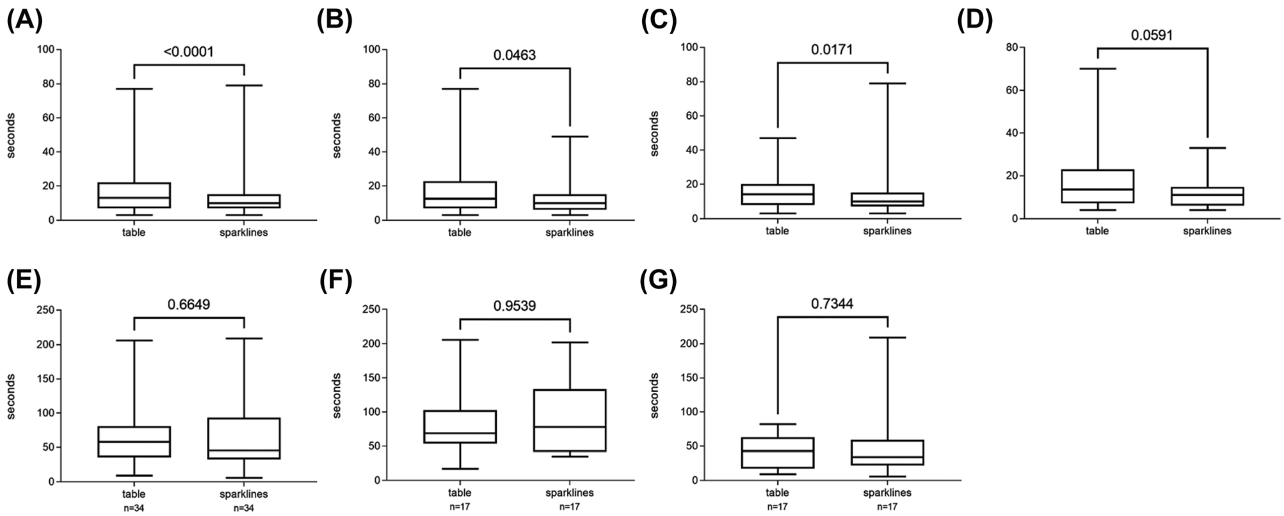

Figure 1: Efficiency (time to answer in seconds) of the cumulative sparkline reports compared to classical cumulative tabular reports.
(A) General questions, overall; (B) general questions, physicians; (C) general questions, students; (D) general questions, nurses; (E) medicalquestions, overall; (F) medical questions, physicians; (G) medical questions, students.

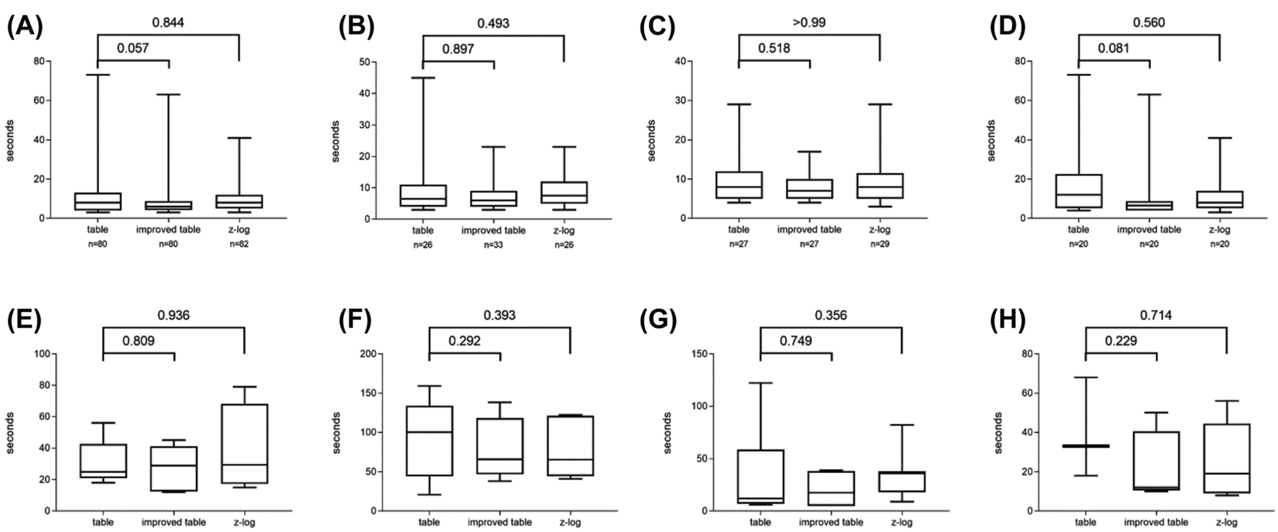

Figure 2: Efficiency (time to answer in seconds) of the improved tabular and the z-log single report formats.
(A) General questions, overall; (B) general questions, physicians; (C) general questions, students; (D) general questions, nurses; (E) medical questions, physicians Fe deficiency; (F) medical questions, physicians β-thal; (G) medical questions, students Fe deficiency; (H) medical questions, students β-thal.

Overall, nearly all general questions related to the cumulative reports could be answered correctly by the 46 participants (efficacy of 90%) (Table 3). However, these answers were given significantly faster using the sparkline format ($p<0.001$), meaning that the efficiency of presenting data as sparklines is superior to an classical tabular format, regardless of the reviewers' professional background (Figure 1). This finding is in line with investigations of Torsvik et al. and Bauer et al. [16, 17], who investigated the effect of different graphical presentations on the velocity of the review process (efficiency). However, when asking medical questions, the improvement in efficiency vanished.

The observed indifferent efficacy levels support the meta-analysis of Schaubroeck et al., who also found no difference of the decision-making performance (efficacy) between "line"-diagrams and tabular formats [18]. Similarly, the efficacy when presenting the sparkline format did not differ from the classical tabular format, neither for general nor for medical questions, which could be considered a success, considering the familiarity bias of the tabular format. Hence, the graphical display of cumulative laboratory data improves the time of finding general information on the report, while not altering the correctness of the result.

The overall efficacy (finding the correct answer to general questions) in single reports, was even higher (92–96%), but did not differ between formats. Subanalyses revealed that the efficacy in unbiased medical students, who had less experience in reading tabular laboratory reports, was similar to those of physicians or nurses, concluding that this finding is free from familiarity bias. The overall efficiency of the improved table format nearly reached significance levels (p=0.057), so that we may assume that there is a trend, although not statistically significant. The z-log format, showing results as deviation from the mean, did not show any statistical difference in efficiency. Considering the bias that the z-log format was completely new to the participants, unlike the improved table format (familiar table as basis with added features), the non-inferiority of the z-log format could lead to the assumption that it may be superior after eliminating this bias by educating participants accordingly before its use. An additional study, either with non-medical participants or accordingly educated medical personnel would be necessary to prove this assumption.

To evaluate if the formats would have clinical impact, apart from more comprehensible or faster readability, we simulated two single reports, one with obvious β-thalassemia and one with iron deficiency anemia, in the three alternative report formats, respectively. Questions concerning potential diagnosis and further medical actions in these, as well as the cumulative report, were presented to physicians and medical students only. Iron deficiency and β-thalassemia in the classical tabular format was correctly diagnosed by 92% and 55% of physicians and by 40% and 0% of students, respectively. In order to interpret these findings, the fact that iron deficiency is far more frequent and therefore easier to identify, needs consideration. Efficacy as well as efficiency remained similar between groups. As the number of participants remaining was quite low, after filtering for physicians and students and randomizing between formats as well as iron deficiency and β-thalassemia, the interpretation of findings within these cohorts might be of reduced validity. Additionally, the students might have had too little experience in interpreting test results medically, especially for such diagnoses as β-thalassemia, which makes interpreting results even more difficult.

Overall our findings suggest that reviewing cumulative reports, aiming to find trends or patterns should preferably be done using a graphical display, while single reports might benefit from some adjustments derived from basic information design, supporting a similar finding of Torsvik et al. [17]. We know from other disciplines that choosing the right visual representation depends on the task that needs to be performed. For the single report, the exact value needs to be analyzed and presenting this value in a structured form like a well-designed table is considered to be among the best options. With respect to the cumulative report, we need to focus on the trend or the development of important metrics over time. And thus, in this case charts focusing on trend information are said to outperform tabular information.

However, since laboratory reports usually consist of test results from a variety of parameters, a combination of trend and single result interpretation may be beneficial (e.g. outpatient with acute symptoms and chronic preexisting conditions). Therefore, an interactive user interface in terms of a UCD, allowing for more information to be displayed on demand (mouse-over effect to include trend information in a graphical format) and the possibility to switch between layouts may be the optimal solution [19, 20]. User, task, patient type, data characteristics and many other variables need to be considered when deciding on the optimal layout [10, 16]. For example, the investigated z-log format or sparkline format is difficult to apply on semi-quantitative or qualitative results (e.g. interpretative comment or conclusion of electrophoresis profile, bone marrow morphology, etc). Such patient dashboards, displaying all vital clinical and diagnostic information about the patient, have been applied in critical care and anesthesia but not in other disciplines within hospitals [1]. On the other hand, care needs to be taken as too much freedom in personalizing individual dashboards may result in accidentally hiding critical information and subsequent patient harm.

Our finding, that identifying general information on the report, such as the patients name, date of birth, trends in test results and others, can be improved by applying common design principles (low data-ink ratio, highlight important information and eliminate all other distractions, putting information that belongs together in juxtaposition, etc), might positively impact misidentification errors. Patient identification errors currently account for about 9% of all errors in the total laboratory process, leading to a rejection rate as high as 0.2% of all samples received [21].

Subjectively, participants in our study favored the alternative formats, even when neither efficacy nor efficiency improved. This finding leads us to believe that with increased familiarity to such new formats, increased efficiency and maybe also efficacy may follow. With exponential digitalization of our daily life, upcoming generations of medical students and young medical professionals are accustomed to modifiable data formatting and modern data processing, and may expect these qualities from the laboratory reporting systems. Some new formats might need a short educational intervention prior to implementation, but essentially a basic principle should be kept in mind when designing new report formats: they have to be intuitive. Information design is like a joke – If you have to explain it, it´s bad!

As the format laboratory reports are issued in is still widely based on local or subjective preferences, we believe that there is an urgent need for respective recommendations or guidelines, in order to standardize and harmonize laboratory report formatting across Europe.

There are some limitations to our study which we want to mention. First, the measurement uncertainty and/or total error, helpful when interpreting the test results as well as the reference change limit, used to identify clinically significant deviations in serial results, were not visualized in either of our improved report formats. These additions would not have been contributing to the outcome of our study, as it was not the subject of our survey. However, we aim to do this in a follow-up study, in which we hopefully will be able to use eye tracking solutions.Second, as the number of participants within the subgroups (medical doctors, nurses, students), which also might be the reason for some non-significances. Finally, we cannot exclude any bias resulting from this being a completely different situation than in routine clinical setting. When being observed, study participants often tend to be extra careful and attentive.

Conclusions

In this study we found that graphical display of laboratory data improves efficiency while maintaining efficacy when aiming to identify configurations, patterns or trends, while the table format might benefit from graphical adjustments in flagging and highlighting. By doing so, user satisfaction and readability improved in all of the presented alternative reports.

We additionally believe that presentation of laboratory reports should be done in context with other clinical and diagnostic patient information and, since medical settings in which laboratory data are being used are so manifold, its presentation has to be flexible to fit the users need. One fact, however, is undisputable: There is an urgent need for standardization.

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