Ergonomic design of new paramedic response bags

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ABSTRACT

A two phase project is described for redesigning and evaluating paramedic response bags, one of the key pieces of equipment used by emergency medical services. Adopting a user-centred approach, Phase I involved first educating active service paramedics about ergonomic principles, and then collaborating with them to conceptualise a new type of response bag, based on separate colour coded kits, each containing related equipment items. Phase II describes a formal evaluation study, involving simulated procedures with a patient mannequin and active service paramedics in a real ambulance. Results indicated subjective preferences for the new bags, where 62% of the paramedics believed it was easier to find equipment in the new bag and 65% preferred the new bags overall. No detrimental effects were attributed to the transition to the new bag. Also discussed are the advantages of the participatory design approach, as well as design guidelines and implications for paramedic operations.

1. Introduction

1.1. Paramedicine

Paramedic services (also known as Emergency Medical Services, or EMS) comprise a complex, often highly stressful working environment involving very sick patients who need immediate medical attention, with paramedics typically being the first point of clinical contact for those patients. Because the discipline of paramedicine is relatively new, much of how paramedics operate is still based on practices inherited from hospital settings. This is despite its critical role in the healthcare system, as well as recognition that those practices are also susceptible to many of the same problems encountered in hospital emergency care centres (Donchin, 2002; Grundgeiger et al., 2014). Furthermore, procedures have not always been modified to accommodate the unique environments in which paramedics work. As a consequence, the health and safety of both paramedics and their patients can be adversely affected (Bigham and Welsford, 2015).

One of the major challenges faced by paramedics is the fact that the places where they find their patients can often be uncomfortable and inappropriate to work in. They therefore frequently prefer to treat their patients inside their ambulance, which, although it has many limitations due to its compactness, nevertheless provides good lighting and a clean and steady work surface. Consequently, when considering process improvement, paramedic services typically pay much of their attention to the design of their ambulances, in spite of the fact that most of their critical work takes place where paramedics first find their patients. Examples of adverse circumstances occasionally encountered include treating patients in a hallway, or at the side of the road, sometimes with limited lighting. Weather conditions are often inclement, including extreme cold, which in turn may compel them to work with extra gloves on. The challenges of working under such physical constraints are also often exacerbated by interruptions from family members or bystanders.

Paramedics’ work requires a high level of technical competence, involving crucial decision making. Once paramedics decide on the procedures to be followed, most of their clinical work is based on the detailed protocols they have been trained to perform (Bitan, 2017). If performed incorrectly, however, interventions can cause serious harm to patients. Paramedics’ work therefore needs to be precise and efficient, but not necessarily rapid.

Studies have shown that adverse events in paramedic services occur at a rate that is similar to that of other patient care areas. For example, Vilke et al. (2007) found that 9.1% of pre-hospital treatments by paramedics involved medication errors that had the potential to be harmful. Yet another often overlooked safety concern is that the paramedics themselves are at high risk for both acute and chronic injuries, to the back, neck, arm and wrist (Maguire et al., 2005; Maguire and Smith, 2013).

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physical strain (Hogya and Ellis, 1990; Maguire et al., 2005). Furthermore, to reduce risks to the paramedics’ own health and safety, their equipment should conform to basic principles of ergonomic design.

1.2. Paramedic response bags

One often overlooked, yet critical piece of equipment is the response bags (also known as ‘jump bags’) in which paramedics carry their equipment. Paramedics tend to carry with them everything they expect to need for the cases they expect to encounter in the field, typically numbering between 100 and 200 different items. For example, for a trauma call they might bring with them a spinal board and restraining straps, while for obstetrical patients they may bring along a birthing kit.

Traditional response bags are bulky, comprising essentially one large compartment, within which items are seldom clearly labelled (See Fig. 1). This can impede rapid access to equipment and also lead to confusion, resulting in incorrect selection of medications, and potentially to significant harm to patients (Grundgeiger et al., 2014; Kupas et al., 2015).

One way to minimise such use errors and thus improve patient safety is to redesign the paramedics’ response bags, under the premise that optimising their layout should increase the likelihood that medications will be chosen correctly and expeditiously. In addition, the small number of individual items within each bag (relative to for example a hospital emergency room) allows reducing the physical size of the bags, with the potential added benefit of modifying their biomechanical balance to reduce paramedics’ exposure to unnecessary physical strain (Hogya and Ellis, 1990; Maguire et al., 2005). Furthermore, selecting materials that can be easily reconfigured should allow customised changes to the bags by local paramedic services, without requiring large budgets for planning and implementing such changes (Bitan, 2017).

1.3. The current study

In this paper we report the results of a two phase project to ergonomically design and evaluate a new generation of paramedic response bags. The first phase of the project was conducted in 2014, as an initiative of the Northumberland County Paramedic Services (NCPS), in collaboration with the University Health Network in Toronto, to equip their paramedics with new response bags. NCPS comprises approximately 120 paramedics serving a population of about 85,000 in Northumberland County, Ontario, Canada. A team of human factors specialists collaborated with paramedics from the service to evaluate and redesign the paramedic bags then in use. In the second phase, in 2015, we again collaborated to perform a usability study of the newly designed bags.

2. Phase 1 - material and methods

Design of new paramedic response-bags

2.1. Planning and design process

Our concept generation procedure comprised two stages: (1) educating a group of paramedics about basic human factors concepts; and (2) collaborating with those paramedics in the design of new bags.

The educational portion of our intervention took the form of two approximately 8 hour workshops delivered to a group of 8–10 paramedics. All of the participating paramedics were at the time serving on a committee whose aim was the procurement of new response bags.

In the first educational workshop the paramedics were given a set of lectures on the basic principles of human factors. Due to logistical constraints, we limited ourselves to introducing them only to the basic concepts of how they could supplement their experience in the field by using science to improve their own work environment. In particular they were informed that, among other things, ergonomics is the scientific study of human–machine interactions in the workplace, and that the primary goal of ergonomics is to design workstations to improve performance while reducing stresses and fatigue (Sanders and McCormick, 1982). To accomplish an ergonomically sound design, one must consider the physiological, psychological, and environmental factors that will affect operator performance and well-being (Kushwaha and Kane, 2016). The design process needs to maintain a comprehensive view of how workers interact with their environments, encompassing the advantages and disadvantages of factors such as lighting, noise, and accessibility to materials (del Rio Vilas et al., 2012). The overriding message was that a poorly designed workplace can cause problems of health, productivity and safety, whereas a well-designed workplace can be expected to manifest itself in terms of, among other things, improved operator safety, efficiency and satisfaction.

In the second educational workshop the committee collectively defined the minimal amount of equipment that would be absolutely necessary to include in the bags, based on the protocols that define the use of each item. Starting with the 2013 equipment standards for ambulance services in Ontario (Canada), it was learned that the list of equipment used by basic life support (BLS) paramedics comprises 115 items (a number that includes such non-clinical items as light sticks and towels), with advanced life support (ALS) paramedics adding another 55 items. We then carried out a review of historical data about the number and types of calls encountered by NCPS, together with the frequency of use of each item during a typical work shift. This revealed that NCPS paramedics often carried with them several duplicate items, resulting in more than the standard service required quantities.

Our redesigned bags were intended specifically for use by a team of two paramedics. We also took into account that in the majority of calls NCPS paramedics take care of only one patient at a time. (For the infrequent NCPS cases involving more than one patient, additional support can be provided within minutes from a supervisor and/or additional teams.) This consideration, in combination with the fact that additional supplementary equipment is always stored in the nearby ambulance, allowed us to reduce the number of discrete items to a quantity that was deemed sufficient for taking care of one patient at a time. In consequence, the equipment packs were divided into two parts: (1) a bag for one patient and (2) a bag for the additional personnel. The former would be intended for use in NCPS cases involving only one patient. The latter would pack additional equipment and be intended for use in those cases where NCPS paramedics must treat more than one patient, for example for trauma calls.

In summary, to ensure accuracy and minimise errors, especially when operating under extreme conditions, the paramedics’ equipment and working environment should ideally be well organised and consistent, allowing them direct and easy access to all the equipment they might need. Furthermore, to reduce risks to the paramedics’ own health and safety, their equipment should conform to basic principles of ergonomic design.

An abbreviated description of the methods and design principles used to design the bags has been reported in Bitan et al. (2015).
time. It is important to point out that at all times the number of items in the bags adhered to regulations set forth by the Ontario Ministry of Health.

2.2. Design guidelines

By regarding the bags as a major integral component of their workstation, rather than simply as an accessory, the paramedics were able to exploit the insights acquired during the educational workshops to propose a set of recommendations for newly design bags, based on the key principle of grouping all items within the bags, by function and by sequence. Those recommendations were consistent with the following set of recognised design principles (Boff and Lincoln, 1988; van Cott and Kinkade, 1972) for the placement of controls (where the term ‘equipment’ has replaced the original term ‘controls’):

- Locate the most important and frequently used equipment where visibility and accessibility are high and activation is easy.
- Group together items that are functionally related in terms of system operation.
- Arrange equipment in order of use for quick and error-free activation (usually top-to-bottom or left-to-right).
- Arrange equipment according to physical or functional inter-relationships.

These principles led to the following primary design objectives:

- All equipment inside the bag was to be stored in kits, each with a specific purpose, as seen in Fig. 2 (This approach was similar to that of Grundgeiger et al., 2014).
- Rather than forcing paramedics to dig within the bag to locate equipment, each kit was designed to be quickly removed from within the bag, to facilitate easy access to its contents while outside the bag.
- To minimise the probability of extracting incorrect items and/or types or doses of drugs, the kits were to be colour coded, through the use of clear high-contrast labels, which would be legible even under limited lighting.
- The kits were to be organised in the bags in a manner that would allow them to be accessed according to the flow of a typical call. In particular, the most easily reachable kits were to be for BLS, while kits for ALS were to be located deeper within the bags.
- Each kit was to be regarded as an integral unit. That is, rather than refilling individual items within the kit following its use, the intention was for the entire kit to be replaced with a newly stocked kit every time any item has been removed. (Replenishing of kits was intended to be performed by logistics support prior to the start of each paramedic team’s shift.)

Additional design objectives defined during the educational workshops as key properties of the new bags were:

- In addition to reducing the number of items, we also analysed where individual items had been stored in each bag. This led to a recommendation for equipment to be re-distributed between the two standard bags – one for Airway and one for Circulation – to split the load as evenly as possible between the two team members (See Fig. 3).
- The equipment was also to be distributed between the two bags in a way that matches the paramedic team members’ positions relative to the patient. One typical such configuration involves one paramedic at the patient’s head, with the Airway bag, and the other one at the patient’s side, with the Circulation bag. For treatments that require both paramedics to work in proximity, however, each bag was also to have some redundant equipment that each paramedic would need for such cases.
3. Phase 2 - hypotheses, material and method

**Evaluation of new paramedic response bags**

3.1. Hypotheses

Following Phase 1, our evaluation study was designed to compare the new bags with the traditional paramedic bags. In recognition of the fact that both bags had already been or still were in actual service, we decided that a summative usability evaluation would be the most appropriate approach, to validate that they meet as many of the requirements described above as was feasible (Wiklund et al., 2015). In particular, this led us to test the following primary hypotheses:

H1. Because the new bags were designed with a new physical profile, including straps that allowed the paramedics to carry them on their back, on one shoulder, or with one hand. In addition, the bags were required to maintain a slim profile, both to increase ease of carrying and to facilitate direct access to all the bags’ contents, as explained above (See Fig. 3.).

H2a. As a consequence of compartmentalising equipment into discrete, easily identifiable kits, it was hypothesised that paramedics would subjectively find it generally easier to locate equipment within the new bags. However, because of the extra steps needed for removing the kits from the new bags and opening them before extracting the equipment, we did not predict any detected preference to be very large.

H2b. In spite of H2a, we nevertheless hypothesised that paramedics would subjectively express an overall preference for the new bags relative to the traditional ones.

H3. It was hypothesised that the mean time taken for locating and extracting equipment from the new bags would not be significantly greater than for the traditional bags. To explain this somewhat unintuitive hypothesis, we note that on the one hand we might have expected the mean time to be greater, since the new bags require the opening of an additional zipper before reaching the equipment. On the other hand, we also expected any such delays to be offset by improved access to the more clearly marked equipment inside. Furthermore, in light of our understanding that paramedics in general emphasise precision and decisiveness ahead of rapidity (Bitan, 2017), we surmised that any performance differences would thus be unlikely to manifest themselves through extraction time. Our decision nevertheless to include this as a metric was due to our perceived obligation to confirm that searching with the new bags would not be significantly slower.

3.2. Evaluation study description

The study, which received research ethics approval from the University of Toronto and was carried out over a period of one week, involved 17 pairs of active service paramedics (some of which were primary care and others advanced care paramedics). The pairs were the same as those that had been assigned as a team for that working shift. All were employees of NCPS and all volunteered to take part.

The study was designed as a high fidelity simulation, conducted within the participants’ own station during one of their regular working shifts, using a dedicated ambulance that was fully equipped with both ALS and BLS equipment. (To facilitate participation, the ambulance containing the study equipment travelled to the various paramedic stations within the service area.) In addition to receiving leave from their regular work for the duration of their time spent in the study, the paramedics also received a small gift as a token of appreciation for their participation.

The study simulated a set of standard paramedic procedures involving both pairs of bags: the traditional response bags, used by NCPS until 2015, and the new bags described in Phase 1, that were deployed in 2015 (and are still being used by NCPS). The primary advantage of

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2 An abridged description of the methods of the second phase has been reported in Bitan et al. (2016).
carrying out the study at that particular time was that the majority of the paramedics had gathered sufficient expertise with the new bags to enable them to offer valid opinions, while at the same time it was assumed that they had not yet forgotten their experiences with the traditional bags. Otherwise stated, our assumption was that all paramedics had comparable acquaintance with both bags, which should have led to valid comparisons using the specified metrics.

Each team carried out two simulated scenarios, both of which were similar to scenarios that they had encountered during either their training or regular recertification sessions. Each of the scenarios simulated a severe deterioration of a patient’s condition, one as a result of acute asthma and the other as a result of diabetes. The patient was simulated through the use of a high fidelity mannequin (Stat Manikin with Deluxe Airway Management Head, by Simulaid).

Both scenarios started with the paramedics carrying their equipment from the ambulance to a nearby office-like environment, where they first treated the patient (mannequin) before carrying him back to the ambulance to continue treatment. Both scenarios required management of airway, breathing and cardiac arrest modalities, and each comprised specific tasks for both primary and advanced care paramedics. (Talk aloud descriptions of participants’ activities were also recorded, but were deemed after the fact not to contain information that might provide insights relevant to our hypotheses.)

The scenarios focused only on execution of the technical aspects of prescribed treatment protocols, rather than on decision making during the procedures. This was done not only so that we could focus on the explicit tasks of locating and extracting equipment, but also in order to prevent the active service paramedics from feeling that they were being examined on their clinical proficiency. This decision was made among other reasons because the simulations were managed by a NCPS employee, one of whose regular roles was to conduct similar simulation sessions for training and certification purposes.

Each scenario (A and B) was carried out with each member of the paramedic team equipped with a different response bag. To counterbalance the order, half of the teams started with the traditional bags and half with the new bags. In addition, half of the teams started with scenario A and half with scenario B. In other words, each team carried out each scenario once, using either the traditional bags or the new bags. Teams were assigned as they enrolled, with randomisation thus achieved by means of the enlistment order.

Videotaping of the simulation sessions was carried out from three different angles: two from suspended GoPro cameras – one carried by the simulation manager and the other by the primary investigator (who also took notes during the sessions) – and a third from a camera mounted approximately 3 meter away on a tripod.

After each session participants filled in a questionnaire that inquired about their preferences and concerns. As shown in Fig. 5, this comprised questions about how participants carried the bags, how easy it was to find the equipment and what were their general preferences. (Note that the term “old bag” was used in the questionnaire as this was the term the NCPS paramedics used at that time.)

4. Results

4.1. Preferences and concerns

To address hypothesis H1 we analysed the video recordings of the simulation sessions. (Although the questionnaire responses were highly correlated with the video recording results, the latter were deemed to be a more reliable source of information.) On the way to the patients at the scenes, all paramedics wheeled the bags on the stretcher. On their way back, while the patient was on the stretcher, the results (based on data from 31 paramedics and summarised in Table 1) showed that paramedics clearly preferred carrying both the traditional and new bags on the stretcher (71% and 52% respectively). Following that, however, the next choice for the new bags was to carry them on their backs (35%), as opposed to the traditional bags, which tended to be carried on the participants’ shoulders (24%).

Due the nature of the response variable and the experiment design that assigned each paramedic to use each of the two bags, a mixed effects multinomial regression model was applied (Papageorgiou and Hinde, 2012a) with bag type as a fixed effects factor and paramedic as a random effects factor. The model was fitted using the mixcat library (Papageorgiou and Hinde, 2012b) in R (www.R-project.org). To test for bag type, the standard log likelihood ratio test was applied. The results ($\chi^2(3) = 20.029$, $p = 0.000$) support hypothesis H1, that there was a preference for carrying the new bags on the back.

The results for questionnaire responses not related to how the bags were carried are presented in Table 2. Addressing hypothesis H2a, the questionnaire results for question 3 showed that 21 of the 34, or 62%, of the paramedics believed that it was easier to find equipment in the new bag. As expected, this result was only ‘marginally significant’ ($\chi^2(1, N = 34) = 1.88$, $p = 0.17$). On the other hand, question 5 (hypothesis H2b) demonstrated a preference for the new bags by most of the paramedics. In particular, in support of hypothesis H2b, significantly more paramedics (22 of the 34, or 65%) said that they preferred the new bags, while only 10 (29%) preferred the traditional bags ($\chi^2(1, N = 32) = 4.5$, $p = 0.034$) (2 paramedics (6%) didn’t answer this question). (In an effort to clarify these results we noted that the responses contributing to the preference expressed for the traditional bag in questions 3 and 5 came from the same two paramedics who, as part of their open ended feedback, remarked that they had encountered some trouble with the kit containing the King LT (laryngeal tube) – in other words, not with the actual redesigned bag per se.)

Due to the extra step required for accessing equipment within the kits, question 4 was included in the questionnaire as a means to allow for potential further improvements in the bag. The questionnaire didn’t provide any other significant results however.

4.2. Search and extraction time measurements

The high fidelity video recordings obtained from the three cameras were synchronised and analysed using Morae video analysis software (by TechSmith) to annotate the paramedics’ actions. Each simulation was divided into six identifiable tasks, such as “find and remove intubation equipment”. For each task, the beginning point (when the instructor gave the order to perform the task) and the end point (when the paramedic handed the instructor all the equipment needed for the task) were identified and assigned time stamps. This procedure was carried out by a research assistant who was blinded to the hypotheses, in order not to introduce any bias into the results.

Tables 3 and 4 present the mean task performance times for each identified task. Because the scenarios were not considered as a separate experimental factor, the execution times for each task were averaged across scenarios. Note that because paramedics were able to exercise judgment in treating their ‘patients’, not every task was carried out in each scenario. This accounts for the fact that the number of occurrences shown in the table are not identical for the two types of bags. Consequently, Table 3 presents the results of the four tasks that all paramedics performed with both the traditional and the new bags, whereas Table 4 presents the two tasks that paramedics performed with only one set of bags.

Although the mean times for equipment extraction with the new bags were generally greater than with the traditional bags, our t-tests did not indicate any significant effect of bag type on mean times, except for the Bag Valve Mask (BVM) task ($p = 0.03$). That is, in spite of the extra steps needed for removing the kits from the new bags and opening them before extracting the equipment, the mean times taken to extract equipment from the new bags were not shown to be greater than the

3The results of questions 3 and 5 have been reported in Bitan et al. (2016).
corresponding times for the traditional bags. However, due to the limited number of samples, we caution that this failure to reject the null hypothesis, although apparently in support of Hypothesis H3, should not be taken as reliable evidence.

5. Discussion and conclusions

5.1. Design of new paramedic bags

The obvious tangible result of this project is a set of new paramedic
The objective performance results of our evaluation study suggest that designing bags that better integrate well with the work carried out by the paramedics very likely improve both their work experience and patient safety. This was due to its transition to the new bag. (It is worth noting that, in addition to the successful deployment of the new bags, paramedics also adopted the new bags subsequent to the completion of our study.)

The subjective portion of the evaluation demonstrated a preference for the new bags, primarily because they are better organised and easier to handle. The paramedics’ responses support that, even though they were able to handle their clinical tasks with the traditional bags, they felt that they benefit from the way the equipment is organised in the new bags.

### 5.2. Lessons learned: the importance of participatory design

It was very evident that our user centric design approach led to improvements in the end product and its successful deployment. One of the key factors contributing to the acceptance of the new bags was the training sessions that introduced the paramedics to the understanding that designing bags that better fit their working environment would very likely improve both their work experience and patient safety. This complemented our decision to include members of the paramedic service in the subsequent phases of the design conceptualisation, prototyping and evaluation processes.

### 5.3. Lessons learned: the challenge of performing a realistic evaluation study

The usability study was formulated to validate the design of the new bags and evaluate them in a controlled environment. That environment on the one hand represented real working conditions for the paramedics and on the other hand allowed us to assess their behaviour in a meaningful way. The challenges of running the resulting evaluation study with practising paramedics and a mobile high fidelity ambulance based simulator should not be underestimated. While it was important to stage an environment that simulated real-life scenarios, multiple logistical challenges and limitations imposed by the different physical locations and facilities made it difficult to maintain complete consistency, as well as to recruit as many teams as originally anticipated.

### 5.4. Lessons learned: the importance of tailoring equipment to specific operational circumstances

Throughout our design process we remained aware of the fact that the new bags being designed might not necessarily be generalisable beyond the specific population of users for whom we were designing them. For example, our design had to adhere to the equipment specifications dictated by the Ontario Ministry of Health. In addition, our design was based on factors such as (a) the average case load of paramedics in Northumberland County, as well as (b) the typical complement of paramedic teams on duty, (c) the types of cases and (d) the number of patients ordinarily dealt with, (e) the availability of backup teams, etc. Otherwise stated, although we stand behind the intrinsic

### Table 1

Frequencies of methods of carrying the bags from the scene (number of respondents, percentage). (Traditional bags had no straps, and thus could not be carried on the back).

<table>
<thead>
<tr>
<th>Preferences</th>
<th>Traditional Bags</th>
<th>New Bags</th>
</tr>
</thead>
<tbody>
<tr>
<td>On the Stretcher</td>
<td>24 (71%)</td>
<td>16 (52%)</td>
</tr>
<tr>
<td>On the Back</td>
<td>0 (0%)</td>
<td>11 (35%)</td>
</tr>
<tr>
<td>On the Shoulder</td>
<td>8 (24%)</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Using the Handle</td>
<td>2 (6%)</td>
<td>2 (6%)</td>
</tr>
</tbody>
</table>

### Table 2

Questionnaire responses.

<table>
<thead>
<tr>
<th>Question</th>
<th>Traditional Bag</th>
<th>New Bag</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Carrying the bags to the scene, which bag felt heavier?</td>
<td>32%</td>
<td>59%</td>
<td>9%</td>
</tr>
<tr>
<td>3) In which bag was it easier to find the equipment needed?</td>
<td>38%</td>
<td>62%</td>
<td>0%</td>
</tr>
<tr>
<td>5) Which bag did you prefer?</td>
<td>29%</td>
<td>65%</td>
<td>6%</td>
</tr>
<tr>
<td>4) Was it easy to find the kits that you used?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very difficult</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very easy</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) The colours were useful for finding the kits needed:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completely disagree</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither Agree nor Disagree</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agree</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completely Agree</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) It was easy to get all kits back into the bag afterwards:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

### Table 3

Mean task performance times, standard deviations, number of occurrences for each task and two sample T-test analyses. Participants performed all four tasks using both sets of bags.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Traditional Bags</th>
<th>New Bags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>5.9</td>
<td>8.9</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>5.2</td>
<td>4.3</td>
</tr>
<tr>
<td># Occurrences</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Intubation</td>
<td>4.1</td>
<td>5.6</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td># Occurrences</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Laryngeal Tube</td>
<td>25.7</td>
<td>27.2</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>12.5</td>
<td>14.4</td>
</tr>
<tr>
<td># Occurrences</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Bag Valve Mask</td>
<td>7.2</td>
<td>13.2</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>2.6</td>
<td>3.8</td>
</tr>
<tr>
<td># Occurrences</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

### Table 4

Mean task performance times, standard deviations, number of occurrences for each task and two sample T-test analyses. Participants performed each task using only one of the two bags.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Traditional Bags</th>
<th>New Bags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventolin</td>
<td>16.6</td>
<td>18.6</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>8.7</td>
<td>10.9</td>
</tr>
<tr>
<td># Occurrences</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Epinephrine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (s)</td>
<td>30.3</td>
<td>41.1</td>
</tr>
<tr>
<td>STdev (s)</td>
<td>13.0</td>
<td>13.1</td>
</tr>
<tr>
<td># Occurrences</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
validity of our design approach, we have no basis for expecting that all of the specific details of our new paramedic bags will necessarily be pertinent to particular operational circumstances of other jurisdictions.

5.5. Implications: some potential impacts of redesigning paramedic response bags

The intervention presented in this study has the potential to directly affect not only the tasks of the paramedics that use the new equipment, but also patients at the receiving end of their treatments. For example, it is reasonable to hypothesise that a more methodically organised response bag is likely to lead to a reduction in the probability of a paramedic extracting an incorrect piece of equipment or, more importantly, an incorrect medication. Although practical constraints prevented us from investigating this factor in the present study, the potential impact of demonstrating such an outcome is obvious.

Another type of improvement that was achieved was in the way the paramedics carry the new bags. Carrying the bags on their back is healthier for the paramedics and might also reduce the chances of hitting a patient with a bag that is carried in an unsecured manner.

At a more general level, it was our feeling during the course of our project that, although difficult to test, the collaborative design procedure that we followed also has the potential to provide an additional payback in the form of an improvement in the safety culture within the paramedic service.

Yet another expected, but as yet untested, outcome of our intervention is the potential for an economic payback from the newly designed bags in terms of facilitating inventory control, as a consequence of increasing the visibility of equipment and medications used for each patient's treatment. In a similar vein, it stands to reason that having a standard, consistently organised response bag should facilitate the interchange of personnel both within paramedic teams and within the larger context of a paramedic service.

5.6. Potential for future studies

The current study focused on the design of response bags—one of the most basic tools used by paramedics. Going beyond this first step, the improvements in response bag design reported here should be part of a broader effort to improve the paramedics' work environment in general, to replace the current ad-hoc circumstances that frequently characterise their working conditions with an optimised environment based on user centred design. One example of such an approach is a study by Ferreira and Hignett (2005) that demonstrated the importance of ergonomic analysis for improving the safety and efficiency of paramedics working inside of ambulances. A related study is Prairie et al.'s (2017) research on the strategies used by paramedics to load stretchers into ambulances.

A thorough review of research on paramedics' activities is likely to reveal a clear emphasis on the biomechanical aspects of their work and how it relates to work accidents (e.g. Prairie and Corbeil, 2014). Going beyond biomechanics, however, future studies should also look at the broader question of how paramedics set up their equipment around the patient, in order to acquire a better understanding of how expert paramedics are able to cognitively map their anticipated use of equipment to their model of the particular case confronting them. Such studies should include not only analysis of the use of response bags but also the entire workstation, comprising the oxygen tank, monitor-defibrillator, and of course, the patient. The present study also suggests that we need to improve our understanding of how paramedics approach consistency and accuracy in following their prescribed treatment protocols. One manifestation of this would be to record data on the important topic of frequencies of errors in identifying and administering medications.

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