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Ergonomics of visual emergency signals

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Visual distress signalling devices should be designed for safe and efficient use by untrained persons under adverse operating conditions. Thus, Ergonomics/Human Factors information should be used intensively to optimise visual emergency signals (VES).

Research was performed to assess the compliance with Human Engineering principles in existing VES. A field survey was conducted, in which the VES were categorised, critical Ergonomics aspects were established and compiled to design recommendations. Laboratory tests were performed that indicated the effects of selected Human Engineering design features on identification, unpacking, and operation of VES. Finally, the research results were validated in realistically simulated emergencies.

The research findings demonstrate that adherence to recommendations is often missing in present VES, but would greatly reduce the time needed (here: up to 80%) for the successful use of the signals.

The US Coast Guard helps about 75 000 yachtsmen yearly who find themselves in a distress situation. Nevertheless, more than 1000 yachtsmen drowned in 1977. In many of these cases, visual emergency signals (VES) are used, or should be used, to indicate the need for help, or the location of the people in distress. For this purpose, flares (aerial or hand-held), smokes (hand-held or floating), lights (powered by batteries or cool chemical reaction), flags and pennants are most often employed. However, use of such VES is not limited to recreational yachtsmen. Similar devices are used to indicate danger situations caused by traffic mishaps. Civilian aircraft and many military aircraft and vehicles are equipped with such VES, hunters and climbers in remote areas carry them for an emergency.

VES should be 'human engineered' very carefully, because they must be recognised, unpacked and operated correctly, quickly and safely by people usually untrained in and unfamiliar with these activities, and under severe circumstances of physical and emotional stress. However, anecdotal evidence as well as references in the literature (McHale, 1977; Miles, 1977) indicate widespread lack of ergonomics considerations in the design of distress signalling devices. Hence, the US Coast Guard sponsored related research which was concluded recently (Kroemer and Marras, 1978). The following text is based largely on this investigation.

In this paper, the terms "Ergonomics" and "Human Factors" are used interchangeably. The term "Human Engineering" emphasises technical application.

Experimental procedures and results

The research was performed in four distinct phases. These are: (1) field survey to collect general information, (2) compilation of human engineering recommendations applicable to VES, (3) laboratory, and (4) field validations to assess the affects of ergonomic design features.

Research Phase 1: Field survey and initial tests

Specimens of VES on the market were bought, and manufacturers and wholsesalers of such devices asked to supply samples and invited to comment on new developments in this area. All together, about 150 different VES were collected, with smoke signals and flares the most prevalent types. Fig. 1 indicates a sample of the variety of VES currently available.

In the initial field test 40 persons were asked to select a named VES from an array of such devices, and to operate it. About half of these tests were performed in a Detroit boating area, the others in the Ergonomics Research Laboratory of Wayne State University. The field tests were neither strictly planned nor highly structured in order not to exclude any factors which should be considered in the later formal experiments.

When confronted with an array of the VES, the persons interviewed were usually surprised and confounded by the large variety of devices. Even the most common signals, ie, hand-held flares and hand-held smoke signals, often caused surprise and confusion when presented together, because their forms, sizes and colouring schemes generally did not give any obvious clues regarding types or use. (The

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Fig. 1 A sample of visual emergency signals

exceptions are flashlights, pistol shaped launchers, and pennants, if taken out of their containers). When asked to select a named device such as a hand-held smoke signal, the subjects usually resorted to grasping at random devices from those displayed, and then tried to read the label which indicated which device they had actually grasped.

When asked to operate a given VES, the subject was usually surprised to find that the manipulation was neither easy nor self-evident. Problems arose often in the removal of the packaging material and then in the actual operation of the device. Removal of protective cover material was always difficult if plastic bags or covers offered high resistance to tearing. Some protective boxes were difficult to open because opener mechanisms were not easily recognised as such, or their operation was complex; for instance, if they had to be pushed and pulled with one hand simultaneously. For the operation of a device it was generally necessary to consult written instructions, which were often difficult to read (eg, black print on dark red background), difficult to understand, and difficult to follow. Subjects made many mistakes, such as twisting caps when supposed to flip them off, pulling in wrong directions, scratching an ignition surface with the fingernail, trying to shoot through the packaging enclosure, etc.

Table 1 lists some of the incidental observations made in the survey phase. Only two of the 40 subjects had ever used marine VES before (smoke signals, hand-held flares). Four persons had used highway flares. This supports the notion that VES should be designed and packaged for use by people who have no training or experience with emergency signals.

Three steps in the use of VES

The observations made in the field survey suggested that the use of VES should be divided into three separate steps. *All* three steps must be performed, and performed in proper sequence, in order to signal. Failure *in any* of them means overall failure, possibly with catastrophic results. *Good* performance in *all* three steps results in quick and correct deployment of the VES.

Identification is the first and often the crucial step in the signalling sequence. Here, the user must determine quickly and accurately what type of VES to select, depending on what it will do, and how it is to be handled. The human factors means used to facilitate identification are commonly called 'coding'. Shape, size, colour, and labels are the main coding features. Non-use, or faulty use, of these cues can prevent or delay selection of an appropriate VES.

The evaluation of existing VES indicated that serious problems exist with respect to identification. When subjects were told to select a specific signal from an array of VES, they often found it difficult and time-consuming to find the device requested. In many cases, form, size, labelling, colouring, etc, did not give a sufficient indication of type and function. (For example, most brands of hand-held flares and smoke signals looked very much alike.) The problem was compounded when packaging material was

Table 1: Examples of observations made in the field survey phase

Excessive time

- It takes subject about 2 min to identify, unpack, and operate a red flare .
- Subject has a great problem in opening a box containing an aerial flare launcher, because the two latches have to be moved towards each other simultaneously
- Eleven wrong attempts until projective flare is selected
- Six incorrect choices until signal launcher is found
- Subject breaks off latch (and almost injures his finger) from box containing flare launcher

Failure

- Subject tries to operate red flare by biting (!) into the device and by striking the scratching surface with the removed paper top
- Subject, after numerous incorrect attempts, gives up attempt to select parachute flare
- Subject is unable to understand the instructions to operate a specially packed aerial flare
- Subject cannot read instructions on flare because they are covered by the end of the pull tape
- Subject tries to activate hand-held smoke signal by scratching ignition surface with his thumb nail
- Several subjects are unable to rip plastic bag from hand-held flares and use teeth to achieve a starter cut in the plastic material
- Subject fails to deploy aerial flare on first attempt, then points nozzle towards his face while pulling on the chain in order to observe success or failure of the deployment

used (boxes or bags, for example) through which the VES could not be seen, or not be seen clearly.

Unpacking is the second step in the signalling sequence. Here, covering (waterproofing) material is removed from the VES. Unpacking procedures must be as simple and quick as possible. They should not require any familiarity with the type of packaging material, or with the opening procedures. Ideally, the unpacking techniques required should be so obvious that no written instructions are necessary. Material selection and design (boxing, bagging, wrapping, shrink-fitting, canning, etc) determine the manipulative skills and strengths required for unpacking. Faulty packaging(such as high resistant material, tightly fitting material that does not offer 'handholds', complex or hard-to-open fasteners) can hinder, delay or prevent successful unpacking.

The experiences with existing VES indicated that unpacking often poses severe problems. Many subjects took unacceptably long times (such as several minutes) to open boxes, or to rip off plastic wrappings, etc. The problems encountered generally resulted from uncertainty regarding where and how to open a package. Plastic wrappers specifically showed the compound problems of requiring high tearing forces while offering very little surface for the fingers to grasp. Starter cuts or pull tabs would have helped, but were generally missing.

Operation is the final step in the signalling sequence. Like unpacking, all procedures needed in the operation of VES must be simple and quickly performed. They should not require prior experience with the type of device, or with the specific operating procedures. Ideally, the steps and manipulations needed to operate a VES quickly, correctly, and safely, should be so obvious that no written instructions are necessary. Coding by shape, size, or colour of the device itself, or of its elements to be held, pulled, flipped off, twisted, screwed on or off, scratched, etc, will determine whether or not a correct sequence of actions is taken, what effort is involved, how long it takes, and if the signal is deployed in time and effectively, or (on the other hand) if the operation is not completed in time, not completed at all, or even results in injury to the user (McHale, 1977).

Many of the VES investigated showed deficiencies with respect to ease, speed, and safety of operation. Subjects found it difficult to understand or follow the instructions given for the operation, either because the instructions were hard to decipher or because the wording of the instructions was difficult to interpret. In some cases the shape of the device itself was unsatisfactory, or the 'trigger' was difficult to operate.

Research Phase 2: Compilation of design recommendations

At this point, the human factors/ergonomics literature was thoroughly examined for guidelines and data applicable to VES. While no complete set of recommendations for signals was found, much existing information is applicable. In particular, ergonomics and human factors handbooks (Chapanis, 1965; McCormick, 1976; Murrell, 1965; Van Cott and Kinkade, 1972; Woodson and Conover, 1964) and US standards for use by the Armed Forces (US 1972, 1974, 1975, 1978) yield much pertinent information. Other sources were also surveyed (ISO, 1978; McHale, 1977; Miller, 1973; Roebuck *et al*, 1975; US Coast Guard pamphlets, literature by VES manufacturers, etc). US Coast Guard personnel and other experts in the field further provided valuable information.*

Design recommendations were compiled for the three steps Identification, Unpacking, and Operation separately (Kroemer and Marras, 1978). They reflect the state-of-the-art in ergonomics/human factors, compiled for ease of use. They can be applied to practically all VES devices, and do not require any radical or very costly re-design of devices, or of their manufacturing methods. In the following, the recommendations have been abbreviated.

Recommendations for form and size of coding

Coding is applied to shape, size, colour of VES, and to their components and packaging. Form and colour coding should be combined to achieve maximum differentiation among various VES, easy identification of a specific VES and clear guidance for unpacking and operation. The specific coding aspect to be emphasised depends on

- The total demands on the operator
- Speed and accuracy with which the device must be identified, unpacked and operated.

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- Space on the device available for coding.
- Number of VES to be coded differently.

Form and size can often be used to indicate the type of VES and to signify its handling characteristics. Unfortunately, at present, form coding cannot be supported by an array of objective criteria because most form coding stereotypes are subjective and not clearly identified. Nevertheless, some coding techniques 'work' even without objectively defined criteria. For instance, the form of a pistol shaped launcher indicates to most people that a projectile will be shot from this device. Therefore, it will be handled in the manner of regular hand guns. Other examples are flares or smoke signals whose shaped handles indicate that they are hand-held devices.

Form and size coding provide visual as well as tactile identification, Visual coding requires that the VES be seen under sufficient lighting, while tactile coding requires that the device be grasped before recognition. Therefore, form and size coding should relate to the visual and tactile senses concurrently.

The following general rules apply:

- Use forms and sizes that are easily associated with, or suggest, the function of the device.
- Use forms that can be easily identified visually and that suggest by their 'tactile qualities' the correct operation ("where to hold, what to do").
- Use forms which are easily distinguished from each other.
- Forms and sizes selected for the ease of operation shall override code considerations for the ease of identification if such conflict arises.
- Use 'openers' and 'starters' such as cuts, tabs, latches, snaps, rings, tapes, buttons and triggers as practical.

All design features, including overall form and sizes, shall ensure that even an inexperienced and weak person can operate the VES in a minimum of time under stressful conditions, such as fear, excitement, darkness, cold, humidity, which might reduce the ability to read, comprehend, or to perform complex motions. Therefore, the following principles guide the design of package and VES:

Unpacking and operation shall require only the simplest and most basic finger-hand-arm motions.

Unpacking and operation shall require only a minimum of muscular strength and skill.

Procedures shall be designed for an untrained and unskilled operator.

The manipulations required in the unpacking should necessitate the use of only one hand.

Tools shall not be required for the manipulation.

Configurations of the hand, and package or VES, can be reduced to five basic groups, indicated in Fig. 2:

(A) Thumb-finger palmar grip

(B) Thumb-fingertip enclosure

(C) Power grip

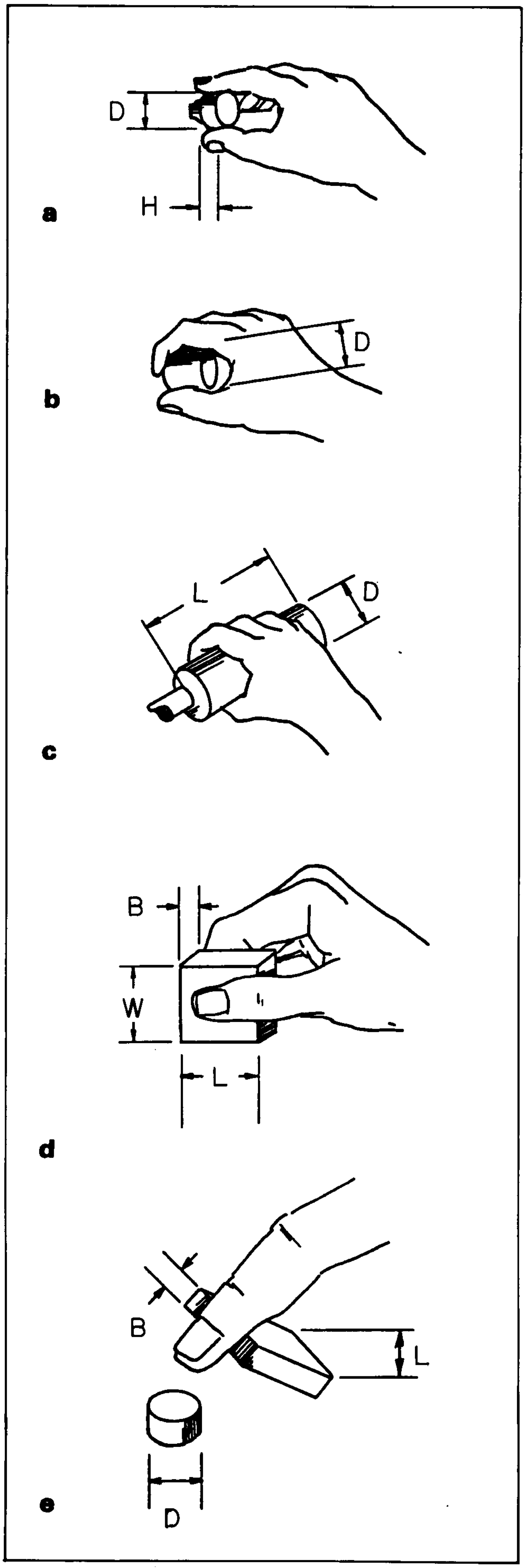

Fig. 2 Five basic grips (adapted from US Army, 1975; and Roebuck, Kroemer and Thomson, 1975)

Table 2: Recommended dimensions and strength requirements (F in newtons) for manipulation of VES (Adapted from US Army 1975, and Van Cott and Kinkade, 1972)

	Grip A			Grip B			Grip C			Grip D				Grip E			
	H cm	D cm	F N	H cm	D cm	F N	D cm	L cm	F N	B cm	W cm	L cm	F N	D cm	B cm	L cm	F N
Minimum	1·25	1	?	1·25	2·5	?	3·8	7·5	?	–	1	1	–	1	1	1	–
Maximum	2·5	10	?	2·5	7·5	?	7·5	–	?	1	–	–	35	2·5*	2·5*	2·5*	12

? : No data available

* : Estimate

(D) Thumb-forefinger side grip

(E) One-finger touch.

There are close interactions between grips used in manipulation, and the dimensions of the package or VES including their elements to be handled. For each of the five grips shown in Fig. 2, Table 2 lists recommended design dimensions.

If flames, heat, slag, etc, develop at any side or end of the VES which could hurt the hand, grips (A) and (B) generally cannot be used: length L for grip (C) must be at least 10 cm. If the device does not require more force in its operation than just necessary to be held in the hand, the minimum diameter D in case (C) can be reduced to about 1 cm.

Recommendations for colour coding

Colours should be used in accordance with population stereotypes to help in the identification of VES to indicate their mode of use. Colour coding is most effective when a specific meaning can be attached to the colour (eg, red for hot) and when it is combined with form and size coding.

The effectiveness of colour coding is severely reduced under low illumination levels. Therefore, colour should not be the sole or primary method of coding, and maximum use should be made of high contrast colours, particularly white letters against black background. In addition to black and white, only five colours should be used for colour coding; red, orange, yellow, green, blue. (In the US, these colours should conform with FED-STD-595.) By patterning colours, such as striping, many distinctive combinations are possible.

Colours should be used as follows:

Red for flaming or hot devices, such as flares, whether hand held or launched. If hand-held, the red colour should be at that part which will be in flames or hot. (On a launcher, the launching side should be coloured red.)

Orange for smoke signalling devices. If hand-held, the orange colouring should be at the part which will emit the smoke.

Yellow or green (yellow-green) for cool lights. If hand-held, the colour should be at the part which will emit the smoke.

White for part(s) intended for safe and correct handling of the device. If the device is not hand-held while in function, no part should be white.

Black for background of labels. Preferably, the black surface should be located so that it separates the active part from the handle.

Combination of colours should be used if a device or part thereof combines several functions for which colours have been designated. The colours can appear in alternating stripes of equal width of at least 1 cm.

Colour of flags and pennants should be visible even when stored or packaged.

Recommendations for labelling (written instructions)

Ideally, VES should be so well coded by form and size that no written text is necessary for quick and correct identification, unpacking and operation. However, instructions must often be provided as aids.

The purpose of labelling is to inform the user about the type of VES, often also indicating its manipulation. Examples: "flag": "flare, hand-held": "smoke canister, floating" "aerial flare".

Labelling requires visual discrimination and therefore sufficient illumination. Labels must always be attached to the device, but additional labelling, for instance on the packaging material, can be helpful. It should conform in style and contents with the labelling on the device.

VES shall be appropriately and clearly labelled for rapid and correct identification, unpacking, and operation. The characteristics of the labelling to be used are determined in general by such factors as

- required accuracy and detail of the information provided
- the time available
- the distance at which the labels must be read (assumed: 70 cm viewing distance)
- the lighting level (assumed: 'darkness', ie label luminance of not more than 0·01 ft L, 0·03 cd/m^2)

Labels should conform to these principles:

Each VES shall be labelled according to its function, if needed, describing the manipulations required for unpacking and operation.

All labelling shall be in the simplest and most direct manner possible.

Labels should give the user all needed information, but only needed information.

Labels should use familiar words.

Labels should be brief, but unambiguous.

Labels should be located consistently on all VES where they can be easily seen.

Labels should read horizontally, not vertically, in regular use.

Labels should supplement other coding procedures, such as form, size, and colour.

Abbreviations and symbols can be employed if advantageous. Capital letters shall be used. Interpunctuation shall be omitted except where needed to preclude misinterpretation. The same abbreviation or symbol shall be used for all tenses and for both singular and plural forms of a word. Numerals should be arabic.

Label characters

- Characters shall be white on black background for high visibility in low level lighting. (This requirement does not apply to trade or manufacturer names, identification numbers, etc, if given on the label.)
- The height of letters and numerals shall be at least 0·4 cm for reading under low level illumination.
- The stroke width shall be $^1/_7$ to $^1/_8$ of the height.
- The width of letters shall be $^3/_5$ of the height, except for the 'I' which shall be one stroke in width, and the capitals 'M' and 'W', which shall be $^4/_5$ of the height.
- The width of numerals shall be $^3/_5$ of the height except for '4' which shall be one stroke width wider, and the '1' which shall be one stroke width.
- Where conditions indicate the use of wider characters, as on a curved surface, the basic height-to-width ratio of 3:5 may be increased to 1:1.
- The minimum space between characters shall be one stroke width.
- The minimum space between lines shall be ½ character in height.

Research Phase 3: Laboratory experiments†

Formally designed experiments were performed in the laboratory to assess the effects of incorporating selected ergonomics design features with respect to performance in the identification, unpacking, and operation of VES. Table 3 lists the experimental variables and tasks. Each of the six variables was presented in three conditions: one that fully complied with human engineering recommendations, one that partially complied, and one that did not comply at all. The designs usually copied features of existing VES. The experiments were conducted under controlled environmental conditions (single subject in an experimental chamber; 80 dBA white noise; 0·01 ft L (0·03 cd/m^2) luminance from the experimental VES). Fifteen male and 15 female subjects participated, none of whom had had any previous experience with VES. They were instructed to perform the experimental tasks as fast as possible. The trial sequences were counterbalanced to avoid carry-over effects.

The performance times were analysed via one-way analyses of variance and t-tests, as appropriate. The results indicated (see Table 4) that design compliance with ergonomics recommendations is directly related to performance time. For the conditions investigated, the well human-engineered designs were handled (identified, unpacked and operated) much faster than the faulty designs.

†See Marras and Kroemer (1980) for a detailed analysis of the experimental research phase.

Research Phase 4: Field validations†

Finally, validation experiments were performed on water. Ten female and 10 male subjects, new to the tests, participated. Each was put in a small life raft on a lake in Michigan and told to rate the visibility of a VES activated on the shore. However, this was in fact a secondary task set up to divert the subject's attention while the rigged raft deflated. When the raft was sufficiently limp, the subject was told to use a VES, placed in the raft for this purpose. Use of the VES required unpacking, twisting off a cap, and scratching an ignition surface.

The VES used were purposely designed to be non-specific, ie, to resemble either a hand-held smoke or flare signal, a combination smoke-flare device, or tube launcher for aerial signal, and to combine several ergonomics design features. Two experimental VES, shown in Fig. 3, were used

Table 3: Variables, tasks, and conditions for tests in the ergonomics laboratory

Test No	Independent variables	Tasks and experimental conditions
1	Shape coding	Visual identification of hand-held flare from six VES, all visual clues but shape removed
2	Labelling	Selection of box containing pistol launcher from array of boxes either unmarked, or labelled with words, or with pistol symbol
3	Design of wrapping bags	Ripping plastic either with a starter cut at edge, or with pull tab, or without any aid
4	Opener design on boxes	Lifting lid of box, either with lift latch, or by pull tab, or with latch requiring simultaneous push and pull actions
5	Legibility of text	Reading and following identical texts, printed in three different contrasts
6	Colour coding	Grasping 'safe' end of devices identical except for different colouring of their ends

Table 4: Results of laboratory tests (average performance times in seconds)

Test No (See Table 3)	Conditions: Design of VES complies with ergonomics recommendations		
	Yes	Partially	No
1	4·01*	5·58	5·50
2	3·86	4·82	4·82
3	18·90	27·33	37·91
4	5·94	23·23	12·89
5	21·67	33·63	55·55
6	3·82	4·56	4·96

* Based on eight trials. All other entries based on ten trials.

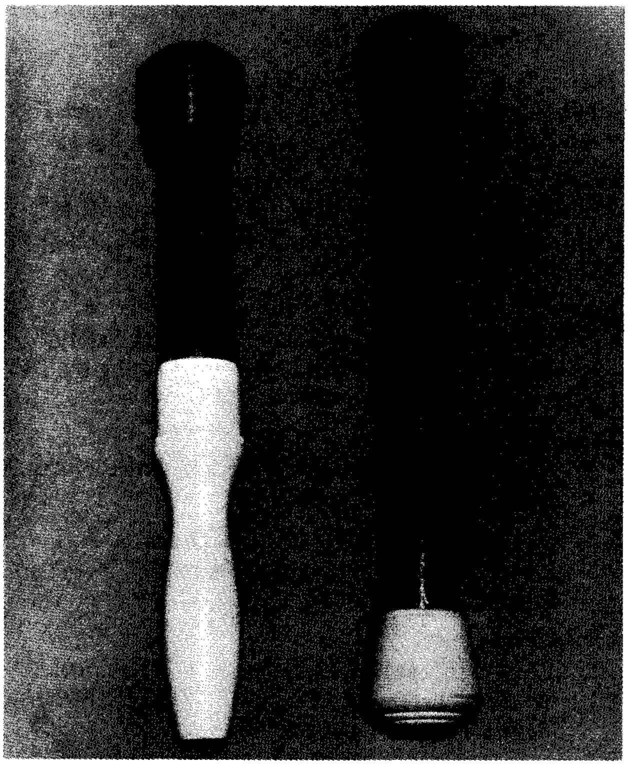

Fig. 3 VES prototypes used in the on-water experiments

alternately. Both were cylinders of 2·5 cm diameter, 25 cm long. One was cylindrical throughout, painted all red, with a rubber cap on each end. It was sealed in a plastic bag without starter cut, or opening tape. The other VES incorporated several human engineering design recommendations: one half was handle-shaped, painted white, the other part was cylindrical and red, its end covered with a cap. Thus it was in contrast to the other VES, unambiguous, colour coded, and shape coded. It was sealed in the same kind of plastic bag, but this one had a tape-closed opening. Each subject operated each VES once, with sex and presentation orders counterbalanced. The times needed to (a) unpack and (b) operate each VES were recorded (see Table 5).

It should be mentioned that the experimental set-up was very successful in creating the impression of a true emergency for the subjects. While there was in fact, no danger (life vests were used, the water was shallow, the raft tethered with a 50 ft (15 m) rope) the impact of water lapping into an increasingly limp and soft raft impressed all subjects.

The times recorded for unpacking and operation were analysed via ANOVA. The results were significant with $p \leqslant 0{\cdot}05$. For the well packaged and designed VES, the total performance times ranged from 0·10 to 0·67 min, mean time 0·29 min. The other VES took between 0·36 and 2·53 min to operate, with a mean time of 1·38 min. The mean unpacking time was reduced by 83% with a starter tape, instead of having a plastic bag with no starter aid. The mean operation time was reduced by 70% by combined shape coding, colour coding, and unambiguous design. These simple ergonomic measures reduced mean performance time by 78% for the total activation (unpacking and operation times combined) of the device.

These reductions in performance times were due solely to the physical features of the device itself, and of its

Table 5: Results of on-water experiments (performance times in minutes)

	Emergency signal designed according to Human Factors principles			Emergency signal *not* designed according to Human Factors principles		
Subject	Unpacking	Operation	Total	Unpacking	Operation	Total
1	0·16	0·05	0·21	0·90	0·56	1·46*
+ 2	0·11	0·18	0·29*	0·72	0·56	0·87
3	0·08	0·02	0·10	0·60	0·04	0·64*
+ 4	0·20	0·03	0·23*	0·81	0·11	0·92
+ 5	0·21	0·03	0·24	0·76	0·05	0·81*
+ 6	0·22	0·21	0·43*	0·20	0·16	0·36
+ 7	0·16	0·26	0·42	0·50	0·92	1·42*
+ 9	0·10	0·06	0·16	1·94	0·38	2·32*
10	0·05	0·06	0·11	0·41	0·39	0·80*
11	0·06	0·04	0·10*	1·98	0·25	2·23
12	0·15	0·10	0·25*	0·52	0·20	0·72
+13	0·10	0·12	0·22	0·44	0·54	0·98*
+14	0·36	0·21	0·57*	1·07	0·32	1·39
+15	0·31	0·13	0·44	1·90	0·63	2·53*
16	0·16	0·19	0·35*	0·32	0·41	0·73
+17	0·15	0·52	0·67*	1·02	0·82	1·84
18	0·12	0·08	0·20	1·17	0·70	1·87*
19	0·13	0·14	0·27*	2·22	0·23	2·45
20	0·18	0·08	0·26	0·42	1·72	2·14*
21	0·14	0·12	0·26*	0·66	0·38	1·04
Mean	0·157	0·131	0·289	0·928	0·448	1·376

+ = Female * = First trial

package, since labelling and instructions were not used. Labelling and instructions, however, had shown significant effects in the previous laboratory experiments on identification, unpacking and operation of VES.

Summary and conclusions

Visual distress signals on the market today come in a large variety of types, shapes, colours, and wrappers. Unfortunately, many of these VES fail to meet even basic ergonomics design principles, and are therefore difficult to identify, to unpack, and to operate even under non-emergency (laboratory) conditions. Adherence to human engineering principles would make the use of VES much easier and faster in emergencies. The results of a field survey, laboratory research, and on-water experiments clearly support this notion.

Ergonomics design recommendations have been compiled, relevant for identification, unpacking, and operation of VES. Adherence to these recommendations would require only moderate re-design efforts. Thus, with relatively small outlay, significant improvements in the usability of VES can be achieved, resulting in more efficient, quicker and safer signalling of an emergency.

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