Usability Testing of a Self-Rescue Respiratory Protective Device

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ABSTRACT:

Respiratory protective device (RPD) is a self-evacuation that has been standardized and tested in terms of mechanical and physical, but it has not been tested in terms of usability. The research aims why usability testing process is crucial for safety product. It covers various aspects regarding the interaction between the product and the user within situations, circumstances and environments. To illustrate how usability testing works, one of the RPD products had been tested with the users under the panic situation. The method for this study was the comparison of usability outcome and the international standard such as European(EN) and Australia(AS/NZ). Thirty subjects were tested with a product in a simulated environment. The observation data was coded by behavioral analysis software then it was concluded in statistical terms. The result showed that the usability testing was effective to detect the product error in conjunction with the EN and AS standard. Moreover, the usability testing covered many aspects that did not mention those safety issues such as ergonomics and usability factors. The author recommends that the usability testing should be an alternative standardization.

Keywords: *Usability Testing, Industrial Standard, Product Safety*

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1. INTRODUCTION

Respiratory protective device (RPD) is a product for the self-evacuation of personnel from smoke-filled or fire-affected environments. RPD had been invented in 1874 by Samuel Barton [1] There are a number of similar products in the market worldwide for self-rescue such as Survivair®-Escape Breathing Apparatus [2] and Emergency Escape Breathing Apparatus-EEBA[3]. The technique and the sophistication of technology employed ranges widely between these products. The availability and amount of oxygen/breathable air supply depend on the scope and purpose of use. There are two main methods of providing RPD: 1) Purifying/filtering the air that a person breathes and 2) Supplying the person with breathable air. This study focuses on the second type. This device works by providing a breathable air supply independent of the ambient air. The breathable air supply can be provided either from a non-contaminated source via air-hose or air-line (not self-contained) or from a portable breathable air supply that can be carried by the person (self-contained) commonly known as SCBA (self-contained breathing apparatus). Breathing apparatus protects against both oxygen deficiency in the ambient air and contaminants in the ambient air (BS EN 133:2001, 2001***).

1.1 RPD for escape

There are seven different types of escape RPD according to BS EN 133:2001with 5 being SCBA. There are 8 types according to AS/NZ 1716:2003*. The suitability of different types of RPD for escape is governed by the type of hazard in the atmosphere. There are foreign standards and guidelines governing the selection, use and maintenance of RPD, such as the AS/NZ 1715:1994, 1994; GB/T 18664, 2002; SABS 220 1988; NIOSH Respirator Fact Sheet and NIOSH Respirator Selection Logic.

1.2 Case study

Air Pack(given name) consists of a heat resistant plastic hood (up to 165°C) incorporating an exhale valve with a mouthpiece made of non-toxic material and aluminium canisters containing compressed breathable air (12 bar, 170 P.S.I., 1 minute duration) with a heat resistance silicone air tube (up to 220°C) as a delivery method as can be seen in figure 2. The product is a self-contained open-circuit compressed air escape breathing apparatus with a hood. When the air in canister is empty, users must change to a new canister by switching the silicone air tube. As a result, the product includes one to four canisters and packed in one package. International standards that are applicable to this product are BS EN 1146 (2001) and AS/NZ 1716:2003 (2003).

*AS/NZ 1716:2003 Respiratory protective devices.
** BS EN 1146: 1997 Respiratory protective devices for self-rescue – Self-contained open-circuit compressed air breathing apparatus incorporating a hood (compressed air escape apparatus with hood) – Requirements, testing, and marking.
***BS EN 133:2001 Respiratory protective devices – Classification

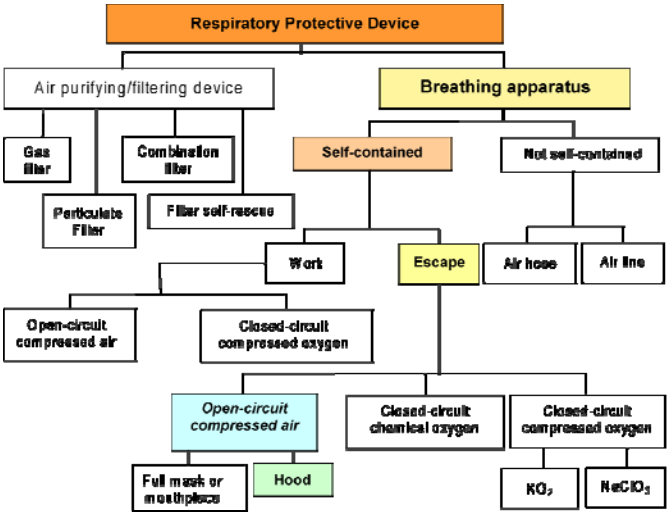

Figure 1: **RPD classification with the Air Fire Pak product highlighted in bold letters**

1.3 Context of Use

It was envisaged that Air Pak should be suitable for using in all building types, especially in workplaces such as hotels, hospitals, factories, banks and schools. It was found that a self-contained escape breathing apparatus with 5 – 15 minutes duration of breathable air supply is suitable for easy access escape (AS/NZ 1715:1994, 1994). It was also found that Thai law states that building occupants should be able to get to a place of safety within 5 minutes of the fire alarm sounding regardless of height or size of the building.

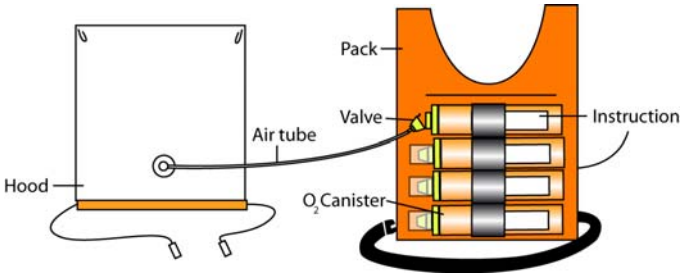

Figure 2 : **Air Pak for Usability Testing**

1.4 Overview of EN 1146 and AS/NZ 1716:2003 specifications

There are many common statements in the content of EN 1146 and AS/NZ 1716:2003 with the same issues and topics and very similar specification details. However, there are a number of significant differences within the two standards. For example AS/NZ does not only specify requirements for visibility, but also states acceptable noise level, where as EN covers visibility issue in great details, but makes no comments on noise level. Table 1 lists the key differences between these two standards.

Table 1 **: Table containig the key differences contained within EN 1146 and AS/NZ 1716:2003**

EN 1146	AS/NZ 1716:2003
One container	One or more cylinders with one or more valves
Pressure indicator compulsory	Pressure indicator optional
5 minutes minimum air supply	At least or less than 15 minutes air supply
Temperature range of -15 – 60°C	Temperature range of -10 – 60°C
Maximum weight 5 kg.	Maximum weight 18 kg. (include work type)
-	Include instruction marked ‘respirable air’ or ‘breathable air’
Instructions shall include the official language of the country of destination	-

It should be noted; however, that AS/NZ 1716:2003 contains requirements for all types of RPD that can be used in Australia and New Zealand, whether it is a work / escape or a filter / air-supply type. On the other hand, EN 1146 is a very specific standard that provides specifications relevant to self-contained open-circuit compressed air breathing apparatus incorporating a hood (Compressed air escape apparatus with hood) only. Therefore it might be said that the key features for such RPD device are that standards have in common. In addition, these standards are not designed to be used isolation, but combine with others as specified within each standard. For example AS/NZ 1716:2003 is to be used in conjunction with, amongst others, AS/NZ 1715:1994, and EN 1146 also list other standards, which are to be used along with it. A number of relevant standards have been reviewed in this study within the defined scope. Only usability specifications were reviewed and assessed; therefore, it was not necessary in this study to review all relevant standards and the client is recommended to assess the product against each relevant standard in order to ensure certification from the target country.

1.5 Objective of the study

- To find out that the usability testing is compatible with the existing standard of self-rescue respiratory protective device by checking with the result of usability testing.
- To propose an issue in the viewpoint of usability testing that does not mention in the existing standard.

2. METHODS

The method of this study has two phases. Firstly, the product was tested with the usability testing method. Currently, there has been usability testing standard for RPD. Then the Air Pak was tested based on task sequence. Second, the analysis of existing standards is compared with the usability testing result. The method of usability testing was a performance measurement [4]. Thirty subjects aged between 20 to 50 years old were participated in this testing. Half of them were male. All subjects had never used this product before and they were randomly assigned to crawl, run, and walk. Test monitors informed them about the aim of testing without telling them how to use the product. Figure 3 is a layout of the testing room. The room was built up as zigzag partitions. Subjects must wear the device at the first spot. At this point, the light condition was low and the firm alarm was activated. After wearing, he or she entered the room covered by smoke. In this room, only the light from fire escape signage was on. Infrared surveillance cameras were installed in the corner of each turn. The image from cameras was captured and analyzed by using the behavioural analysis software called The Observer® [5]. The software was used to analyze the behaviour based on time duration and error analysis. The result was a statistic output of subjects' performance in terms of effectiveness and efficiency.

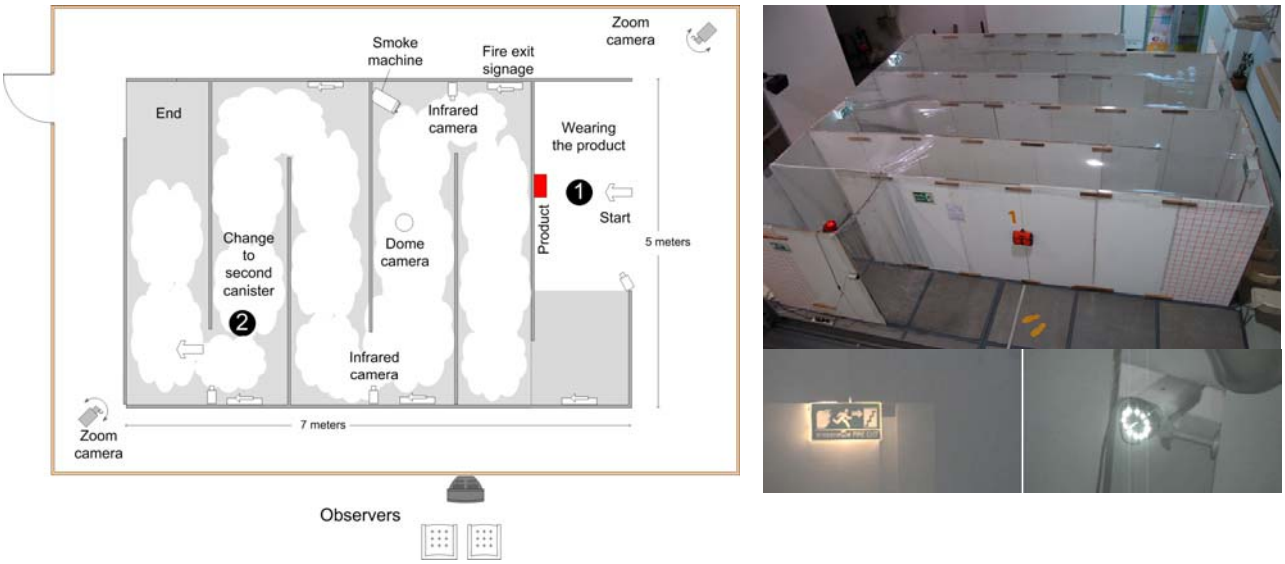

Figure 3 **: Room planning and equipment**

2.1 Error Analysis of Air Pak

The error analysis of Air Pak was scoped to contain only usability risks as it was not appropriate to analyse safety risks. Usability risks included errors or inappropriate actions that could reduce the effectiveness, efficiency or satisfaction of the use of the product. The following external error modes were identified as potential error types in the use of the product: 1) Not done, 2) Too late, 3) Inadequately, 4)Too little, 5) Too much 6)Too late, 7) Mis-ordered and 8) Wrong act performed.

3. RESULTS

3.1 Result of Usability Testing

3.1.1 Effectiveness

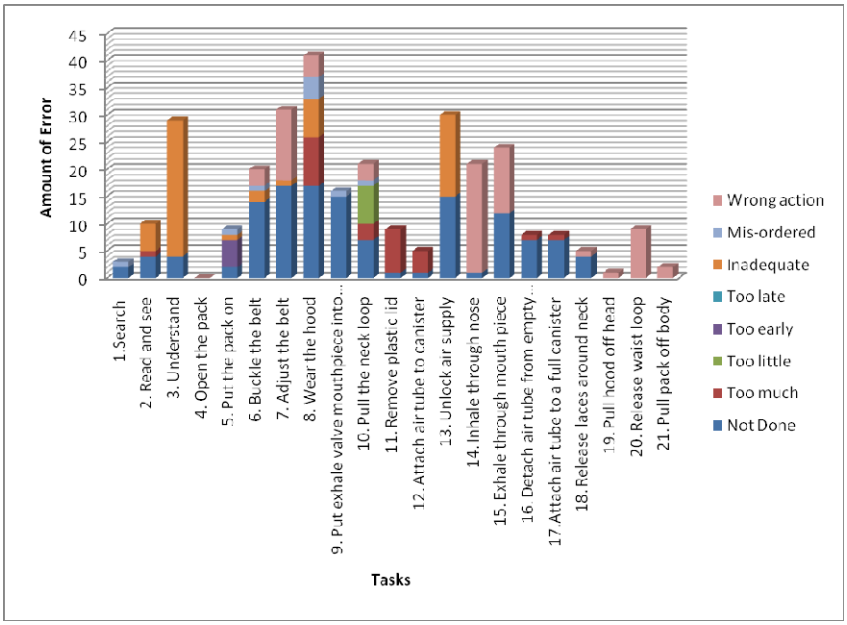

***Figure 3* : Amount of error in each task**

Figure 3 presents that the most errors are from the task of wearing the hood, adjusting the belt, unlocking the air supply, understanding the instruction, exhaling through nose and inhale through nose. Most error was from the error of 'not done'. Many subjects did not know that they could not achieve the goal of each task. For example, subjects did not unlock the air supply by pressing the button into the lock state. As a result, there was no air in the hood while testing. The reason came from the ergonomic problem since the button was hard to press (the force more than 36 newtons). Subjects must press the button until the valve is locked then the air is not out. This point did not include into the EN1146 and AS/NZ1716. The regulation of standard said that the air container should be open either by a quick opening valve but not say how much force or the valve must stay in the ready state when operating. Another severe problem is from the hood since the hood should be properly used without problem. The problem of the hood is about to protect the smoke. The Air pak used the lobe to tighten the hood. Some subjects forgot to tide this lobe and some of them had over tided. Moreover many subjects were afraid to put the hood that looks like plastic bag on the head. This relates to the cultural issue that does not include into any standard.

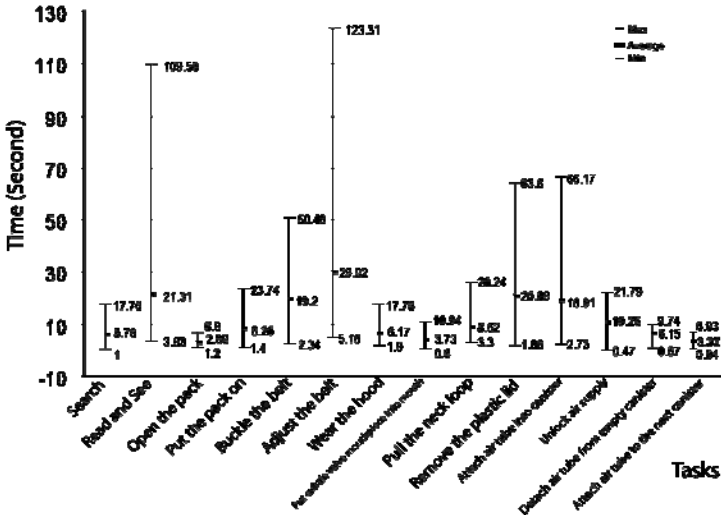

Figure 4 **: Time spent on each task**

Figure 4 presents the time of all tasks. There are several tasks consumed time such as reading and seeing the pack, adjusting the belt, attaching air tube into canister, removing the plastic lid, and buckling the belt respectively. Most of the time spending is unproductive time. Subjects spent much time on adjusting the belt or reading the instruction. When comparing with time and error, amount of error and time was quite correlation excepting the task of wearing the hood and unlocking the air supply. The time spending of both tasks was less but the error was quite extremely high.

3.1.2 Efficiency

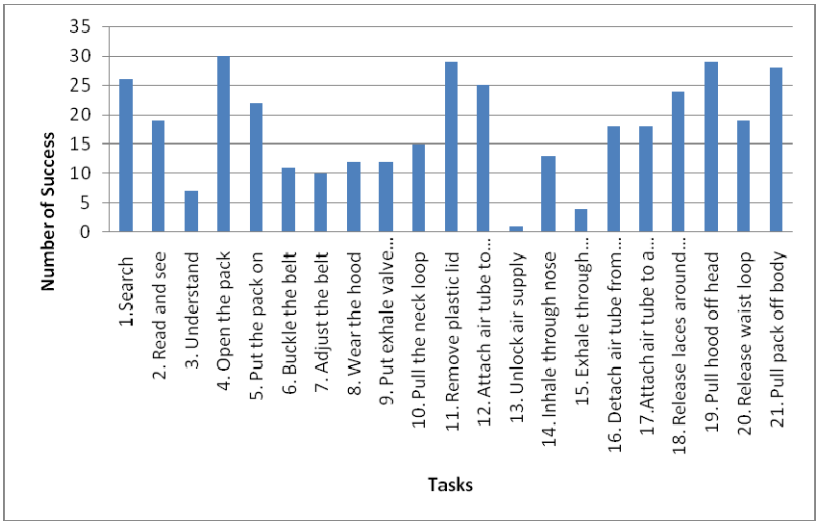

Figure 5 **: Number of subjects who success in each task**

Figure 5 presents the number of subjects who successes in each task comparing with subjects who cannot success the task. The most success task are opening the pack, removing the plastic lid, pulling the hood off the head, and pulling the pack off the body. On the other hand, the task of unlock air supply, exhale through the mouth piece, understanding an instruction are less success. For the conclusion, the rate of failure is more than the rate of success.

3.2 Result from comparing standards

In order to understand how usability fit to the existing standard, the EN 1146 and AS/NZ 1716 is listed as items. There are 56 items that can be tested with usability testing or reviews by specification of the Air pak. After the product was tested with usability testing, the result also presented the outcome of testing in terms of fail or pass.

Table 2 : **Comparison analysis of European, Austrasia standard with Usability/Ergonomic issue**

	Heading	EN 1146	AS/NZ 1716:2003	Usability issue found
1	Classification	Self-contained open-circuit compressed air breathing apparatus incorporating a hood.	Escape-set compressed air self-contained breathing apparatus.	○
2	Definition	A respiratory protective device that is independent of the ambient atmosphere and has a portable supply of compressed air. The exhaled and excess air passes without re-circulation from the hood via the exhalation valve to the ambient atmosphere.	A portable respirator which supplies air from a source carried in one or more cylinders and is released through a pressure demand and breathing tube to a hood from which exhaled air passes through a non-return valve to the atmosphere.	○
3	Component	A hood	A full face piece, half face piece or head covering	○
4		An exhalation valve assembly	An exhalation valve assembly	○
5		An air supply hose	A breathing tube and pressure hose or pipe	○
6		Compressed air container	One or more cylinder of compressed air and one or more cylinder valve.	○
7		A harness	A body harness means of securing the apparatus wearer.	○
8			A pressure gauge or indicator	○
9		A continuous flow device		○
10	Duration of air supply	The rate working duration in steps of 5 minutes	Nominal effective life equal to or less than 15 minutes	Air supply is only 4 minutes maximum. √ •
11	Working temperature	Shall work with a temperature range -15 to 60 °C	Shall work with a temperature range -10 to 60 °C	Cannot test with usability testing ×
12	Design safety	In the ready for use state the hood shall be securely attached the apparatus.		Subjects spent time to attach the air tube into hood. √ •
13		In the ready for use state, the compressed air container shall be open either by a quick opening valve.	The flow of air shall commence with the opening of the cylinder valve or air supply device.	The valve is difficult to press for locking the air supply. Activation force required for pushing downwards with a thump should no more than 34.6 N (5% tile UK female age 11-15)√ •
14		It shall not be possible to inadvertently open the valve when not in use.		The lid covered the valve is difficult to open because uses do not try to pull instead of twist. √ •
15		The opening device shall be secured in the open position against accidental closing.		No problem with the accidental closing because user needs to push hardly. √ +
16		It shall not be possible to don the hood without first activating the air supply		Users cannot operate the equipment easily after wearing the hood. Human error: User can forget to activate air supply which could result in suffocation. √ •
17		The apparatus shall not be fit with a supplementary air supply control device which may reduce the duration of the apparatus.		○
18		The exposed part shall not be made of aluminium, magnesium that gives rise to frictional sparks capable of igniting.	Respirators shall not have exposed metal components manufactured from magnesium, titanium, and others.	Cannot test with usability testing ×
19		If the apparatus has been opened, a clear indication of this shall be given on the outside of the apparatus.		The indicator sign on the plastic was teared when it was opened. √ +
20		The carrying container and the locking device shall be adequately protected against or be resistant to corrosion.	The apparatus shall be constructed from durable components and the vital parts of the apparatus shall be protected.	Cannot test with usability testing ×
21		Materials which come to direct contact with the wearer's skin and the breathable air shall not cause irritation.	Material which may come in contact with the skin should be nonstaining, soft, pliable and not likely to cause skin irritation.	User feels comfortable of wearing the hood. √ +
22	Hood	Hood shall be attached securely to the apparatus.		Hood is difficult to find since it was hided in the bag. √ •
23		Hood shall be designed so that it can be donned and removed readily.		Time of wearing and removing the hood is short. √ +
23.1				Hood should be designed that user do not feel harm when using it. √ •

√ Can be tested with usability testing, × Cannot be tested with usability testing, ○ Reviewed by the specification, + Pass the test, • Fail the test

	Heading	EN 1146	AS/NZ 1716:2003	Usability issue found
24	Exhalation valve	Exhalation valve shall function properly in all orientation		No problem and it can be observed √ +
24.1				Most subjects did not know that they need to breathe out by the exhalation valve. √ •
25	Air supply hose	Shall be flexible and non-kinking.	Shall be flexible and resistant to kinking.	Hose is not kinking. √ +
26		Shall permit free head movement.	Shall permit free head movement without interference to facial seal of the respirator.	No problem √ +
27		Shall not restrict or close off the air supply under chin, arm, or pressure.	Shall not unduly restrict or close off the air supply by chin, arm movement or pressure.	No problem √ +
28		Consists of a full face piece, an exhalation valve and an inlet valve.	Consists of a full face piece, an exhalation valve and an inlet valve.	No problem √ +
29	Compressed air container seal	There shall be only one seal or other technical provision to open total air stored.		The total air cannot be opened by only one seal or technical provision. √ +
30		The seal or its equivalent shall be opened easily by hand or automatically when starting the apparatus.		The container seal is difficult to open. √ •
31		The opening device shall be designed so that it cannot be closed inadvertently.		The device cannot be closed inadvertently.√ +
32	Pressure indicator	The apparatus shall be equipped with a reliable pressure indicator which shall indicate the maximum filling pressure in the compressed air container.		There is no pressure indicator so subjects did not know when the air is empty. √ •
33			The size and position of the pressure measuring device shall be such that it can be easily read by the wearer when the apparatus is being worn.	There is no pressure indicator so subjects did not know when the air is empty. √ •
34			The design of the read-out should be such that it can easily read in low-light conditions.	The graphic is legible to read in low light condition. √ +
35	Body harness or waist belt		All adjusting devices shall be constructed so that once adjusted they will not slip advertently.	The belt is difficult to adjust since the adjustable mechanism is behind the back. √ •
35.1				Subject misunderstands and do not know how to wear the waist belt. They spent too much time on this. √ •
36	Don/Remove	Shall be simple and reliable construction and as compact as possible.		The pack is difficult to wear. √ •
37		The apparatus shall be capable of being donned and put into operation simply and without undue exertion in difficult conditions.	The harness shall be so designed to be adjustable and enable the wearer to don and remove the apparatus quickly and easily without assistance.	The canister should be positioned between 600-420 mm from the head loop of the product for optimum grip and push/pull strength. √ +
38		Harness shall be designed to allow quick, easy and correct donning of the apparatus without assistance.		Many subjects cannot find the harness belt so it takes time to wear.√ •
39	Visibility	The hood shall not distort vision.		Test the vision before and after wearing. No distortion. √+
40		Mist shall not substantially impair vision.		Cannot test with usability testing ×
41	Mobility	Shall be designed to ensure its full function in any orientation.	Do not unduly impede the wearer when walking in a crouching attitude, crawling, or manoeuvring in confined areas.	Subject can walk, crawl and run without impeded. √+
42	Comfort	Shall be designed such that there are no protruding parts or sharp edges.	All parts shall be finished smooth and free from sharp edges and from irregularities that could be potential hazard or cause discomfort to the wearer.	The sharpen edge is in the valve. √•
43			Permit to be worn without undue discomfort.	Subjects are comfortably when they wear the hood. (rating scale) √+
44	Weight	The complete apparatus shall not exceed 5 kg.	When fully charged and ready for use shall not exceed 18 kg.	The canister is made from aluminium so the total weight is not heavy. √+
45	Instructions	Shall be precise and comprehensible.	Be unambiguous.	The instruction is not clear enough and requires interpretation. √•
46	Pictogram	Instruction for use should be complemented by an easy to identify picture on the carrying container showing the donning procedure.	The instructions for use should be complemented by an easy to understand picture on the carrying container showing the donning procedure.	Some of pictogram does not talk how to exhalation valve. √•
47		Size of pictogram should be at least 3 x 3 cm.		The size is large enough to see. √+
48	Content	Type identification marking 'SINGLE USE ONLY'	Type identification marking 'SINGLE USE ONLY'	Subjects can find the marked.√ +
49		Shall be clearly marked 'FOR ESCAPE ONLY'	Shall be clearly marked 'FOR ESCAPE ONLY'	Subjects can find the marked.√ +
50		Related working duration shall be clearly marked.		The letter is too small. √•

√ Can be tested with usability testing, × Cannot be tested with usability testing, ○ Reviewed by the specification, + Pass the test, • Fail the test

	Heading	EN 1146	AS/NZ 1716:2003	Usability issue found
51		Marking shall be as clearly visible and as durable as possible.		The marking is clearly visible. √+
52			Shall be marked 'respirable air' or 'breathing air' or similar wording.	Many subjects do not understand the meaning of Urgent Air. √•
53		Instruction for use shall be in the official language of the country of destination.		User can understand the picture instead of foreign language. √ +
54		Instructions for use shall contain: application/limitation.	Instructions for use shall contain: application/limitation.	Instructions contain the limitation. ○
55		Instructions for use shall contain: determination of the end of rated duration.		The instruction contains the end rate of duration. ○
56		Instructions for use shall contain: checks prior to use, donning and fitting and use.	The instructions shall include correct assembly of respirators.	Instruction should contain incorrect assembly as well as correct one. √ +
56.1				Location of instruction should be easily to look and should not be obstructed while wearing the pack. √

√ Can be tested with usability testing, × Cannot be tested with usability testing, ○ Reviewed by the specification, + Pass the test, • Fail the test

Table 2 is an analysis of the EN and AZ standard comparing with the result of usability testing. Many items in EN and AZ could be tested with the usability. As all items, 12 items could be checked by the specification. 21 items failed while 23 items passed the usability test. 4 of the items cannot be tested with usability testing. Those items are related to physical testing of material such as working temperature(see 11), type of material(see 18), corrosion(see 20), and visual legibility(see 40). 40 items can be tested with usability testing. There were some items found by usability testing that could not be found in the international standard. Item number 13 relates to the ergonomics since the valve was difficult to press. Subjects must use a lot of force to press the button. Item number 23.1 is related to the psychology and cultural belief on the product. Many subjects feel harm when they use the Air Pak, since they believe that the plastic bag is harmful when air is empty. Item number 24.1 suggests that many subjects did not know how to breathe out from the exhalation valve since this item related to the background knowledge of users. Then the product should inform or design in such a way that users know how to breathe in and out. Item number 35.1 shows that subjects did not know that the strip is a belt. Many of them thought that it was a neck loop. The problem is that the buckle belt was too small and the buckle location was unclear. The buckle location should be located in the centre of waist instead of beside. Item number 56.1 suggests that the location of instruction should properly be attached on the place that could easily be read while wearing the pack.

4. CONCLUSION

EN and AZ standard can be tested compatibly with Usability Testing method. With usability testing, the problem of product can be found more especially the issue of ease of use and communication. In term of emergency situation, the users' emotion is crucial such as panic. The usability can be used to test since it relates to the psychological issue of product usage. Although usability testing is not standardized for specific product, the task sequence can be a benchmark for testing. In the future, the product should be tested in terms of safety, usability and ergonomics.

5. REFERENCE

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