

Children & Infants Respiratory Protective System - CHIRPS

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ABSTRACT

Children & infants' respiratory protective system (CHIRPS) is a new innovative respiratory protective system (RPS) against chemical and biological (CB) hazards, designed to fit newborns, infants and children up to 10 years of age. The system is designed as a protective hood which is closed around the neck and integrated with a personal 45 lpm blower. The blower supplies filtered air and creates a positive pressure and an efficient air turnover within the system, thus providing a high protection factor and preventing a CO₂ concentration increase. The CHIRPS was designed to replace the current Israeli infants' RPS and the children's RPS and unite them into one RPS, thus relieving the financial and logistical burden of handling a dual-RPS market for the entire Israeli children population. The CHIRPS' design goal was to improve user-friendliness and functionality of the RPS for all children's ages compared to the current children's RPSs. Furthermore, for economical reasons the aim was to base the design on the current children RPSs' components. The CHIRPS underwent various examinations and trials, including protection factor and functional trials in order to achieve the Israeli certification as an Israeli children and infants' respiratory protective system. Since the CHIRPS was designed for the children's population, human trials were limited and were reduced to the minimal necessity, hence functional trial only. The functional trial was conducted upon 35 children, ages 6 months-10 years old. The CHIRPS was highly functionally evaluated in comparison with the relevant current children's/infants' RPS and was warmly accepted by the children and their parents. The CHIRPS' design yielded a smaller system's volume, compared to the current children's RPSs (which are also integrated with a 45 lpm personal blower), thus was approved to be respiratory safe. The CHIRPS's protection factor was tested upon four different children representative dummies (newborn, 1, 4 & 9 years old) connected to a breathing simulator machine. The CHIRPS was proved to provide a high protection factor for all children's ages (above 800,000). To conclude, the development of CHIRPS has produced a unique innovative breakthrough in children and infants' respiratory protection against CB hazards.

Keywords: CHIRPS, CB, respirator, children, infants.

INTRODUCTION

The government of ISRAEL is required by law to provide its inhabitants with respiratory protection equipment (RPS) against chemical and biological (CB) attacks. This policy led to decades of development of respiratory protective systems designated for the civilian population, a unique users' population which is not accustomed with daily RPS usage and which will be required to use it under

psychological stress in case of an emergency. Giving the unique characteristics of the civilian population, designated RPSs for civilians should integrate a high dynamic reliable protection factor with instructional simplicity and user friendliness.

Amongst the civilian population, the children's population, from newborns until school age, requires a special consideration due to the heterogeneity in cognitive and motoric abilities, as demonstrated in Figure 1 as well as due to the following reasons:

1. An anthropometrical difficulty of fitting young children with a sealed RPS.
2. Psychological and behavioral aspects regarding the difficulties arising from RPS usage, such as breathing resistance, communicational disturbances etc.
3. Psychological difficulty of grasping RPS usage concepts - the need for protection, sealing and comfort.

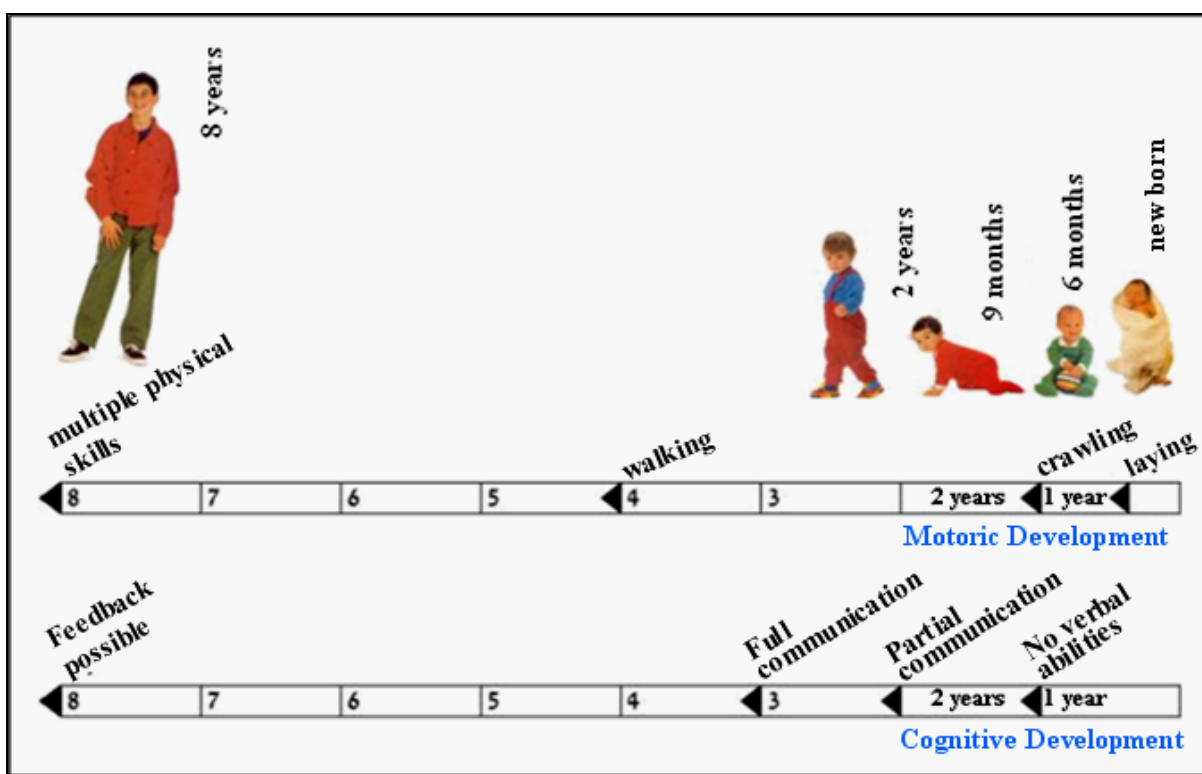


Figure 1. Motoric and cognitive development of children.

An analysis of all of the considerations mentioned above on one hand and the acquired Israeli experience of fitting facial masks to the children's population during the 70's on the other hand, have produced the understanding that the most efficient and safe way of providing the children's population with CB protection has to rely on an over-pressure hood concept.

Respectively, during the 80's the development of two designated children's RPSs was completed - the Children Hood Blower System (CHOBS) for children at the age of 3-8 (Figure 2) and the Chemical Infant Protective System (CHIPS) for newborns and children until the age of 3 (Figure 3).



Figure 2. Children Hood Blower System (CHOBS)

Figure 3. Chemical Infant Protective System (CHIPS)

Both RPSs are based on a hood/semi-suit which is connected to a personal 45 lpm blower. The blower supplies filtered air and creates a positive pressure and an efficient air turnover within the system, thus providing a high protection factor and preventing a CO₂ concentration increase. In both RPSs' development projects the human engineering and user suitability factors were emphasized in order to provide the children with maximal comfort and a toy/costume image while maintaining sufficient RPSs' volume and air capacity in order to ensure maximal protection and safety levels.

During the years, both RPSs have created a heavy financial and logistical burden upon the Homefront Command which was required to change the RPSs every few years according to the children's ages. Furthermore, the acquired civilian population experience with the children's' RPSs has revealed the need for functional and user-friendliness improvements in those RPSs.

CHIRPS - RPS DESCRIPTION

Children & Infants Respiratory Protective System, CHIRPS (Figure 4) is a new innovative children & infants' RPS against CB hazards, designed to fit newborns, infants and children up to 10 years of age. The RPS' donning and doffing is done by an adult (the parent).



Figure 4. CHIRPS - Children & Infants Respiratory Protective System.

The main requirements for the CHIRPS' developments were as follows:

1. One uniform children's RPS for 0-10 years of age.
2. Respiratory safety and protection factor levels identical to those of the CHIPS and the CHOBS.
3. Improved human engineering factors (functionality, comfort, communication, feeding and drinking) compared to the CHIPS and the CHOBS.
4. Long shelf life, minimal maintenance and reduced costs.

Due to those requirements the CHIRPS' design aspired to meet the physical characteristics of the CHIPS and the CHOBS, hence to maintain or improve the dead space volume, air capacity and overall RPS resistance, and for economical reasons to rely on their components.

Like the CHIPS and the CHOBS, the CHIRPS is designed as a protective hood which is closed around the neck and integrated with a personal 45 lpm blower. The blower supplies filtered air and creates a positive pressure and an efficient air turnover within the system, thus providing a high protection factor and preventing a CO₂ concentration increase.

RPS' components

The RPS is comprised of different components. Most important of which are detailed henceforth.

1. Hood

- a. The hood constitutes the RPS' shell. It's made from a soft flexible laminate providing chemical protection. The hood's cut is comprised of 3 parts - two rear cuts and one frontal cut. All the RPS' components are integrated upon the hood and the zipper and neck seal enclose the protective shell.
- b. The RPS' cuts were carefully designed both to maintain the volume and air capacity of the Israeli children's RPSs, in order to ensure identical respiratory safety and protection factors levels, and to anthropometrically fit the children's population starting from female newborns of the 5th percentile until 8 years old boys of the 95th percentile.

2. Zipper

- a. In order to create an open RPS which will be user friendly and will not threaten the fitted children, the design integrated the RPS with a rear zipper. The zipper allows fitting the child with an open RPS and then closing it in order to seal it.
- b. The zipper is integrated with a long pulling lace in order to enable the RPS' closure in a laying down babies' posture, as demonstrated in Figure 5.
- c. The inner side of the zipper is covered with a laminate strip which prevents hair clutch in the zipper during its closure.

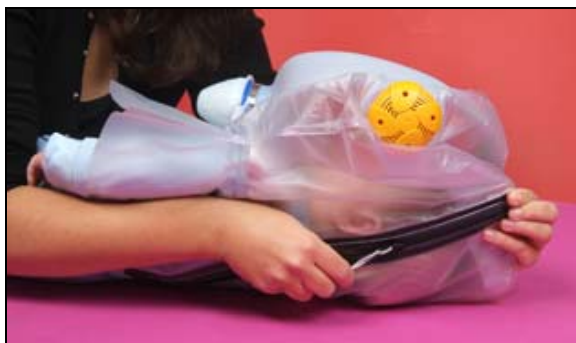


Figure 5. Zipper closure in a laying down babies' posture.

3. Neck seal

- a. The neck seal opening was designed in accordance with the children anthropometric characteristics. Upon babies, the neck seal is loosely placed at the lower part of the neck and upon the shoulders. Upon 8 years old boy of the 95th percentile the neck seal is comfortably placed around the neck.

4. Visor-mount assembly

- a. In order to simplify the RPS' integration process, a visor-mount was designed. All RPS' components are assembled upon the visor-mount, hence visor, air inlet assembly, drinking/feeding assembly and the outlet valve assembly, as shown in Figure 6.
- b. The visor allows a good field of vision and enables personal eye glasses usage.

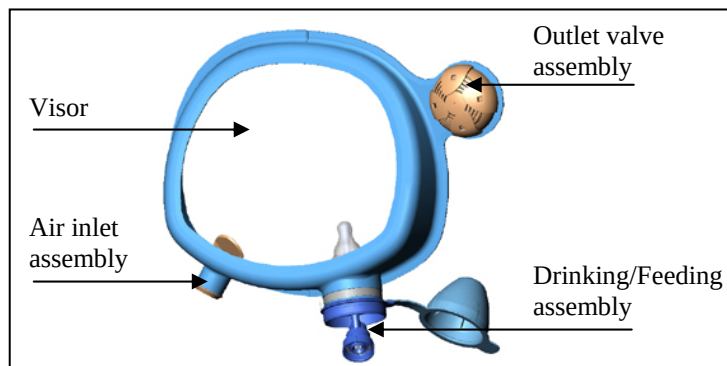


Figure 6. Visor-mount with all integrated components.

5. Drinking/feeding assembly

- a. In order to allow maximal comfort of the RPS usage, an adjustable drinking/feeding (DF) assembly was designed (Figure 7). The assembly can be directed to the user's mouth by pulling/pushing and tilting the drinking bottle. Therefore, when the DF assembly is not needed, it is located beside the user's face, causes no disturbances to the user and do not affect the field of vision.



Figure 7. Feeding/drinking using the DF assembly.

- b. The DF assembly was designed to fit both drinking through a straw and feeding with a nursing bottle. As such, it consists of an adjustable nursing bottle's nipple which can be directed to the baby's mouth using the inner drinking straw. When the nipple is no longer needed, it could be removed and the child could drink directly through the drinking straw.

- c. In order to ensure the DF assembly sealing from the environment while not in use, the drinking straw was integrated with a spring valve. Only the connection of the designated drinking bottle to the drinking straw opens the valve and enables fluids passage.
- d. All the DF assembly components can be easily removed and re-assembled on to the visor-mount, in order to enable their cleaning and disinfection for repeated use.

6. **Blower mounting assembly**

- a. The anthropometrical, motoric and skeletal diversity amongst the children population obliged two kinds of solutions for the blower mounting - one for babies and the other for walking toddlers and children (Figure 8).
- b. The designated blower mounting for babies transfer the blower's weight, during the baby's carrying by the parent, to the parent. It is designed as a back mounting which is fitted to the child like a rucksack, using shoulders and waist adjustable straps.
- c. Bigger walking children can carry the blower's weight by themselves. Therefore, they can use the waist mounting which was designed as a waist belt with a designated blower's connector.
- d. The blower is mounted upon both back and waist mountings by inserting its mounting clip into the designated connector on the different mountings.

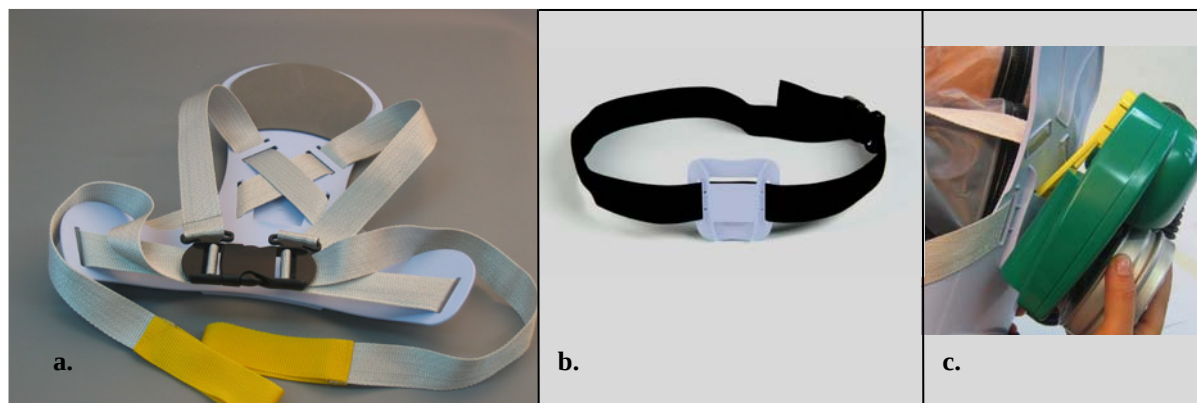


Figure 8. Blower mounting assembly: a. back mounting; b. waist mounting; and c. blower's mounting clip insertion to the designated mounting's connector.

CERTIFICATION TRIALS

The CHIRPS Israeli certification was obtained after various examinations and trials, including the testing of protection factor, respiratory safety and functional evaluation. Since the CHIRPS was designed for the children's population, human trials were limited and were reduced to the minimal necessity, hence functional trial only. The remaining certification trials were conducted upon different children representatives' dummies.

Respiratory Safety

The CHIRPS' dead space volume and air capacities were examined in comparison with those of the CHIPS and the CHOBS. The dead space volume examination was conducted by measuring the volume of rice needed to fill up the hood. The head volume of an 8 years old child of the 95th percentile was reduced from the hood's volume for the CHIRPS and the CHOBS comparison. The head volume of a newborn of the 5th percentile was reduced from the hood's volume for CHIRPS and CHIPS comparison. The obtained value defined the dead space volume within the RPSSs.

As detailed in Table I, the CHIRPS design yielded a smaller system's dead space volume, compared to the current children's RPSs.

Table I. Children RPSs' Dead Space Volume

Child's age	CHIRPS 0-10 years	CHOBS 3-8 years	CHIPS 0-3 years
Newborn	9.2 liters		15.0 liters
8 years	7.1 liters	12.0 liters	

The air capacities provided by BL-45B blowers from the two Israeli manufacturers integrated with a M-80 canister were examined in the CHIRPS compared to the CHIPS and the CHOBS. The results are detailed in Tables II and III.

Table II. Air Capacities in Children's RPSs – SHALON BL-45B Blower

Child's age	CHIRPS		CHIPS/CHOBS	
	Capacity (lpm)	Pressure (mmH ₂ O)	Capacity (lpm)	Pressure (mmH ₂ O)
Newborn	45.10±0.73	6.29±0.13	45.65	4.48
2 years	43.31±0.90	7.44±0.32	46.19	4.49
8 years	42.93±1.02	7.63±0.49	44.35	6.15

Table III. Air Capacities in Children's RPSs – IMPERTECH BL-45B Blower

Child's age	CHIRPS		CHIPS/CHOBS	
	Capacity (lpm)	Pressure (mmH ₂ O)	Capacity (lpm)	Pressure (mmH ₂ O)
Newborn	45.55±0.99	6.78±0.20	48.44	4.82
2 years	45.63±1.20	7.91±0.19	47.76	4.74
8 years	45.23±0.82	8.08±0.31	45.10	6.44

As shown in the tables above, the CHIRPS has a smaller dead space volume and similar obtained air capacities to the CHIPS and the CHOBS using the BL-45B blower. Therefore, the CHIRPS was approved to be respiratory safe.

Protection Factor

Protection factor is defined as the ratio between the measured aerosol concentration of the protection factor test chamber ambient air and the measured aerosol concentration inside the RPS (C_{out}/C_{in}). Fit factor is calculated for each and every exercise and is defined as the harmonic average of n protection factors measured during a certain exercise. The average fit factor is the harmonic average of m fit factors which were calculated for the different exercises.

$$FF_{exercise} = n / \sum (1 / PF_i)$$

$$FF = m / \sum (1 / FF_{exercise})$$

The protection factor trial was performed at the Protection Factor test chamber at the Israeli Institute for Biological Research (IIBR). The test system was comprised of:

1. 5x2x2.5 m³ aerosol chamber designated for protection factor trials conduction upon 2 subjects simultaneously.
2. An ATI/DTA, model 4B aerosol generator which creates a corn oil aerosol concentration of 20-26 mg/m³ of 0.4-0.7µm Mass Median Aerodynamic Diameter (MMAD) particles.
3. An air sampling system, which samples air from the nose and mouth area within the mask via the mask's drinking tube and transfer it to 2HF model detectors (made by ATI) for analysis.
4. Designated software for data accumulation, analysis and protection factors calculations.

Normally the protection factor certification trial is conducted upon a representative group of the RPS' users. In this case, since the users are children this could not have been done. The Medical Corps and the Israeli Ministry of Health did not approve children's exposure to corn oil aerosol. Therefore, the CHIRPS' protection factor was tested upon four different children representative dummies (newborn, 1, 4 & 9 years old) connected to a breathing simulator machine (Posichok manufactured by Biosystems). The CHIRPS was tested upon all representative dummies in comparison with the CHIPS and the CHOBS. All RPSs were tested at their defined work module, hence with their defined personal blower (BL-45B for CHIRPS and BL-45 for CHIPS and CHOBS).

The protection factor trials included normal and strenuous breathing as detailed herewith. All RPSs were tested with the appropriate normal breathing characteristics of the different representative dummies' ages. The breathing characteristics of children are as follows:

1. Respiration volume of each breathing cycle amongst children can be approximately defined as 10 cm³/kg body weight.
2. The characteristic numbers of breathing cycles per minute for the different ages are detailed in Table IV.

It is important to stress out that the breathing simulator machine couldn't provide a tidal volume (breath volume per one breathing cycle) smaller than 0.5 liter; therefore the minimal tidal volume was 0.5 liter. This value is strict regarding newborns. Another aggravation of the test's conditions compared to actual human usage conditions was the addition of 4 liters suction of air from the RPS to the detectors which caused a lower over-pressure level within the RPSs compared to an actual human usage. Furthermore, since the protection factor was tested upon representative dummies, which cannot perform various simulating exercises for movements and physical effort, the test's conditions were exacerbated and the protection factor was tested in an additional breathing regime in which the breathing rate was increased to 1.5 times bigger than the characteristic breathing rate of all different ages. Every test contained 5 identical exercises of 1 minute breathing, during which 150 measurements were taken per exercise and their harmonic average was reported as $FF_{exercise}$. Every RPS was tested 3 times with regular and increased breathing rates. Between tests the dummies were extracted from the test chamber and the RPS was doffed and re-donned.

Table IV. Breathing Rate of Children

CHIRPS / CHIPS (breaths per minute)			CHIRPS / CHOBS (breaths per minute)		
Age	Boys	Girls	Age	Boys	Girls
0-1	31±8	30±6	4-5	24±3	24±3
2-1	26±4	27±4	5-6	23±2	22±2
2-3	25±4	25±3	6-7	21±3	21±3
			7-8	20±3	20±2
			8-9	20±2	20±2

The CHIRPS was proved to provide a high protection factor for all children's ages (above 800,000), similarly to the CHIPS and the CHOBS as shown in Table V.

Table V. Fit Factors of CHIRPS in Normal and Increased Breathing Rates in Comparison with CHIPS and CHOBS

Age	CHIRPS	CHIPS	Age	CHIRPS	CHOBS
Normal breathing					
Newborn	1,000,000	164,440	4 years	1,000,000	997,572
1 year	1,000,000	570,170	9 years	1,000,000	981,007
1.5 times increased breathing rate					
Newborn	828,607	161,018	4 years	1,000,000	1,000,000
1 year	995,962	307,443	9 years	992,460	1,000,000

Functional Evaluation

The RPS' requirements obliged the conduction of a functional trial with children volunteers of all relevant ages, in order to evaluate to RPS' user-friendliness and comfort. It was defined to be a comparative trial to the CHIPS and CHOBS in order to examine the functional improvements of the CHIRPS. The functional trial was conducted upon 35 children, ages 6 months-10 years old. During the trial the children were asked to done the RPS and stay with it for a whole hour, and then, for comparison, wear the CHIPS/CHOBS according to the child's age for an additional half an hour. During this time the children enjoyed playing assembly and thinking games, painting, coloring and watching movies.

The functional parameters were evaluated on a scale of 1-5 (5=best/better) through a subjective questionnaire, which was filled out by the parents and their children. The CHIRPS was evaluated both on its own and in comparison with the CHIPS/CHOBS. In addition the volunteers were asked to write down their preferable RPS. The results are detailed in Tables VI and VII.

Table VI. Comparative Functional Evaluation of CHIRPS and CHIPS/CHOBS

Parameter	Average score	Parameter	Average score
Preparation for use	4.06	Personal eyeglasses	4.00
Donning comfort	4.67	Pressure upon body	3.33
Staying comfort	2.89	Drinking	4.21
Hearing	2.72	Pacifier use	5.00
Speech comprehensibility	2.67	Doffing comfort	4.22
Vision	4.00	Safety feeling	3.33
Visor fogging	3.29	General comfort	3.72

Table VII. Functional Evaluation of CHIRPS

Parameter	Average score	Parameter	Average score
Preparation for use	4.79	Personal eyeglasses	4.67
Donning comfort	4.59	Pressure upon body	4.30
Staying comfort	4.41	Drinking	4.27
Hearing	3.85	Pacifier use	3.33
Speech comprehensibility	3.91	Doffing comfort	4.88
Vision	4.82	Safety feeling	4.71
Visor fogging	4.73	Packaging for re-use	4.31

As shown in the tables above, in most parameters the CHIRPS was functionally found to be preferable or identical to CHIPS/CHOBS, emphasizing its preference in donning and doffing comfort. The CHIRPS was found to be slightly inferior to the CHIPS/CHOBS regarding hearing and speech. Nevertheless, the CHIRPS was highly functionally evaluated and was warmly accepted by the children and their parents, whom all of which have responded that the CHIRPS is their preferable RPS for children.

Additionally, the functional trial results have proved that the CHIRPS fits children from newborn up to 10 years of age.

CONCLUSIONS

To conclude, the development of the CHIRPS has produced a unique innovative breakthrough in children and infants' respiratory protection against CB hazards. It was designed to replace the current Israeli infants' and children's RPSs and unite them into one RPS, thus relieving the financial and logistical burden of handling a dual-RPS market for the entire Israeli children's population. The CHIRPS was proved to be user-friendly and functionally comfortable for the children and their parents. It was proved to be respiratory safe and to provide the children with a high reliable protection factor.

Acknowledgements

IDF HomeFront Command
IDF Logistic Technologic Branch
IDF Ground Forces