23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

HUMAN-CENTERED DESIGN APPROACH IN THE DEVELOPMENT OF TRANSPORTATION DEVICES FOR LOW BIRTH WEIGHT INFANTS AT HOSPITAL DISCHARGE

Cindy Janneth Rondón Cachopo
University of Campinas
cindy@fem.unicamp.br
Antonio Celso Fonseca de Arruda
University of Campinas
celso@fem.unicamp.br

Abstract. *"Low birth weight infants" should be transported under special conditions after hospital discharge. These special conditions are associated with physiological immaturity and low weight state that encourage the need of differentiated retention devices of conventionally existing products. A human-centered design approach was used to develop two solutions for the "low birth weight infant" transportation, a solution for usage in particular vehicles and another for usage in collective vehicles. The goal of the current study was to improve the transportation of "low birth weight infants" at hospital discharge. This report describes the methodology employed in the design process and the conclusions found with this approach. The findings indicated that the existing "child restraint devices" on the market do not appear to meet the needs of "low birth weight infants". The developed solutions maintain in the children a correct ergonomics posture and more comfortable and safe relative to existing solutions. The users show high satisfaction in relation to the developed solutions. The human-centered design appears to show high effectiveness to conduct the development of human-centered projects, especially projects directed to a vulnerable or minority group of the population, which usually present special needs.*

Keywords: *human-centered design, low birth weight infants, product design.*

1. INTRODUCTION

In Brazil in 2011, around 16000 children (newborns to 1 year of age) were dead in motor vehicle accidents (Waiselfisz, 2014). With the aim of prevent these deaths and injuries, children younger than 7.5 years of age are now required by 277/08 resolution in Brazil to be restrained in car seats or "child restraint devices" appropriate for their weight while in motor vehicles (*Conselho Nacional de Trânsito*, 2008).

Although infants who are involved in collisions as car passengers are less likely to be injured or die if they are restrained in these sitting devices (World Health Organization, 2013), several studies have highlighted the problems that "low birth weight infants" may face when using conventional "child restraint devices" (Bull and Stroup, 1985; Côté *et al*., 2008; Joffe and Hall, 2006; Willett *et al*., 1986). In Brazil, each year, about 233 053 "low birth weight infants" born (UNICEF BRASIL, 2013).

Bull and Stroup (1985) documented that a few of standard "child restraint devices" did not allow for proper positioning of 2 kg infants because the straps distances were too long. Cotê *et al*. (2008) founded a risk of upper airway obstruction in infants in sitting devices. Joffe and Hall (2006) annotated that "low birth weight infants" are at risk of suffering episodes of apnea, bradycardia and oxygen desaturation if transported in "child restraint devices". Willett *et al*. (1986) concluded that "child restraint devices" may place small infants at risk for significant hypoxia and ventilatory compromise due to the tendency for infants carried in these seats to slouch.

Clearly, over time, the technological advances of "child restraint devices" to small infants has slowed. In fact, the fundamental design of the "child restraint device" has remained largely unchanged for at least 20 years. This is despite recent research, which has highlighted issues with existing designs that should and could be improved, including ergonomics properties, to allow ability of the seat to fit the size of the infant and proper positioning of the infant.

The goal of the current study was to improve the "child restraint devices" for "low birth weight infants" through the design intervention of this restraint device. In addition, as it was been observed that several newborns are transported in collective vehicles in the family members' arms and with great difficulty, this study also has the aim: to develop a solution to improve the transportation of "low birth weight infants" in collective vehicles, where children are not required by law to be restrained in restraining devices.

A design approach that emphasizes diversity of the characteristics of the different users groups and their necessities fits with a human-centered design philosophy (Abras; Maloney and Preece, 2004). Human-centered design fundamentally means that solutions should be designed through of an understanding of the needs of users. Furthermore, these solutions must adapt to the characteristics of the users.

This report details a human-centered approach to the design of solutions to the “low birth weight infants” transportation. This approach began with acquiring an understanding of the needs of different user groups as they perform different tasks that are carried while “low birth weight infants” are transported in a specific environment to cope these needs. By following this procedure, the solutions developed with human-centered design can improve the “low birth weight infants” transport.

2. METHODS

Figure 1 shows the model of human-centered design approach that was followed in four phases: (1) specific the context of use (understanding the current conditions of “low birth weight infants” transport and the needs of the users), (2) specify the requirements (translate the needs of the users to requirements that the solutions must meet), (3) produce design solutions, (4) evaluate the designs. The model was based on the phases of the NBR ISO 9241-210 user-centered design methodology (*Associação Brasileira de Normas Técnicas*, 2011).

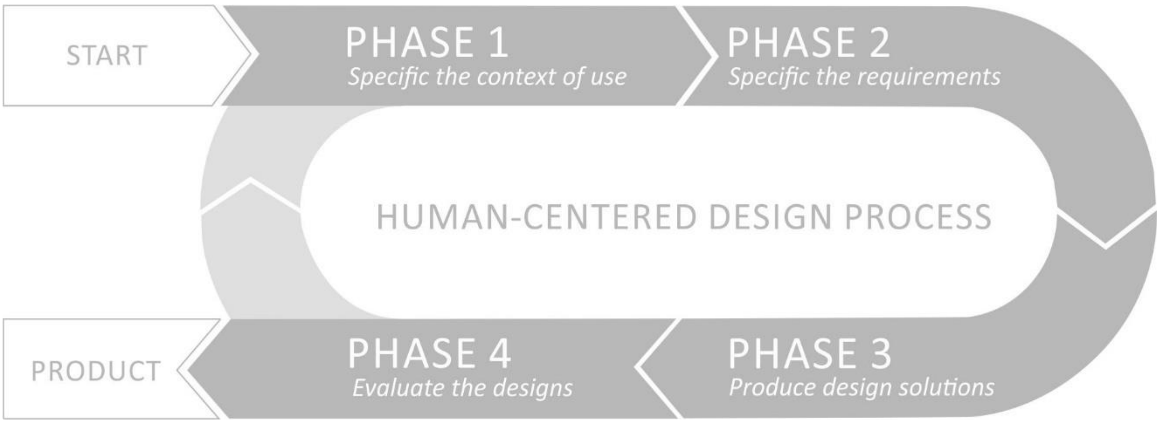


Figure 1. Human-centered design process model (Cachopo and Arruda, 2015)

The design process was conducted according to the requirements of the CNS nº 466/12 resolution. Approval was obtained from the Research Ethics Committee of the University of Campinas and from Brazil Platform. Participants provided written consent when joining to the process. Specific inclusion criteria were set for the different activities. As illustrated in Fig. 2, each of the phases of the design process included a set of activities and will be further elaborated in the following sections.

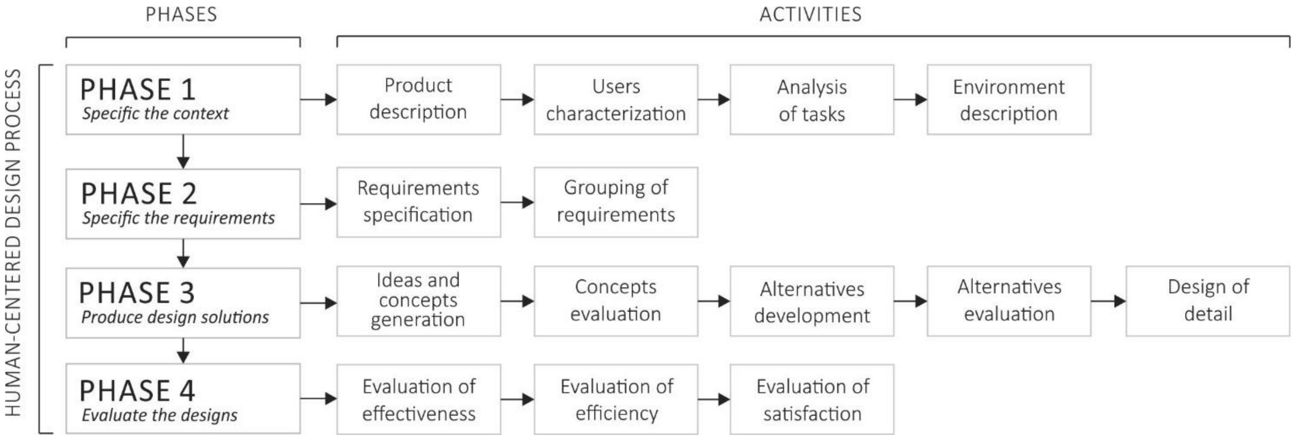


Figure 2. Human-centered design process activities (Cachopo and Arruda, 2015)

2.1 Product Description

The process started with a product description to have an understanding of the state of the art. This activity was effectuated the analysis of three types of existing products through literature reviews. This three products types, that are related with the infant transport, were: “child restraint devices”, “pillow insert” and “baby carrier”. For each product type, seven different products were analyzed, identifying their characteristics, advantages, disadvantages and origins. The information obtained from this activity was analyzed in order to obtain a list of user needs.

2.2 Users characterization, analysis of task and environment description

The remaining activities of the Phase 1 focused on three factors: the users, the user tasks and the transportation environment. These activities was achieved through a field study conducted at the Integral Care for Women's Health – CAISM, hospital of the University of Campinas. This field study involved a structured interview in person with 6 NICU nurses, *in situ* observation of the transportation of ten "low birth weight infants" (with weight from 1600 g to 2500g) in automobiles and five "low birth weight infants" in collective buses and unstructured interviews with family members of the observed "low birth weight infants". The number of the study participants is within the described by Macaulay (1996) and Nielsen (1993) who recommended from 4 to 9 participants to focus group interviews and to found usability issues.

Through the transport observation was possible to identify issues of the current transport conditions. A procedure was used to rate the risk and severity of these issues and those that had the highest ratings were targeted in the improvement of the transport.

With the information collected in this field study, was possible to characterize the users, to analyze the tasks conducted for users, to describe the environment in which the tasks were conducted and essentially, to identify user needs.

2.3 Requirements specification and grouping of requirements

Based on the user needs identified in Phase 1, a set of design requirements was formulated and grouped in use, function, structural, technical-productive, formal and identification requirements. These groups were followed in the development of design solutions.

2.4 Ideas and concept generation

With this activity of the design process, the first synthesis of the results of previous phases was generated through conversion of requirements to ideas. Then these ideas were improved and turned in design concepts.

2.5 Concepts evaluation

Design concepts were evaluated and selected the bests through a focus group interview. Five graduation students of the faculty of mechanical engineering of the University of Campinas were invited to take part. The concept evaluation was structured in two parts. The first part involved to evaluate the design concepts of solutions to transport with use of "child restraint devices", while the second part consisted in to evaluate the design concepts of solutions to transport in collective vehicles.

The concepts evaluation consisted in to compare concepts in relation to the essential qualities that should characterize them (adaptability, reliability, manufacturability, aesthetics, ease of use, functionality, innovation and portability) through a "decision matrix" (Ullman, 2009). The results of this comparison were the argument of taking decision in the concepts selection. Six concepts were selected in total, three for transport with use of "child restraint devices" and three for collective transport.

2.6 Alternatives development

Based on the concepts evaluation, the selected concepts were detailed and have gone from a two-dimensional representation to three-dimensional models.

2.7 Alternatives evaluation

Design alternatives were evaluated and selected the bests through a focus group interview. This activity was conducted at the Integral Care for Women's Health – CAISM, hospital of the University of Campinas. In total five participants joined this evaluation: two healthcare professionals and three "low birth weight infants" family members. The alternatives evaluation was structured in two parts. The first part involved to evaluate the design alternatives of solutions to transport with use of "child restraint devices", while the second part consisted in to evaluate the design alternatives of solutions to transport in collective vehicles.

The alternatives evaluation consisted in to compare design alternatives in relation to the essential qualities that should characterize them (adaptability, reliability, manufacturability, aesthetics, ease of use, functionality, innovation and portability) through a "decision matrix" (Ullman, 2009). The results of this comparison were the argument of taking decision in the alternatives selection. Two concepts were selected: one for transport with use of "child restraint devices" and one for collective transport.

2.8 Design of detail

The aim with this activity was to refine and to detail the chosen alternatives. Based on the alternatives evaluation, two designs was done and the final solutions to "low birth weight infants" transportation was developed. During this activity was achieved: to detail components and the ensemble of the design solution, to detail the functions of the design solution, to design of visual identity, to specify the manufacturing process and to develop user manual and build prototypes.

2.9 Evaluation of effectiveness, efficiency and satisfaction

The design effectiveness and efficiency and user satisfaction were evaluated as part the design process. These activities took place at the Integral Care for Women's Health – CAISM, hospital of the University of Campinas and were achieved through a field study. This field study was structured in two parts. The first part involved *in situ* observation of the solutions use in the transportation of ten "low birth weight infants" (with weight from 1600 g to 2500g) utilizing "child restraint device" and five "low birth weight infants" (with weight from 1600 g to 2500g) which are transported in the arms of a family member. While, the second part involved a satisfaction questionnaire with participation of 15 family members of the infant that was observed.

Through the transport observation, was possible to know if the "developed solutions" countered the issues encountered in the Phase 1. A procedure was used to rate the risk and severity of these issues and the obtained ratings were compared with the obtained ratings in the Phase 1. This comparison allowed identify the extent in which the developed designs improve the "low birth weight infants" transport.

3. RESULTS

This section introduces results from the main phases of the design process.

3.1 Phase 1 and Phase 2

The state of the art analysis allowed to know that a wide part of the products that were studied, contain materials that produce excessive sweat in the infant because these materials are not "breathable materials". In relation to "child restraint devices", the deleting of the "low birth weight infants" in the current products development was evident due to the dimensions of these products are very large for the infant size. Furthermore, several products suppliers do not specify the minimum infant weight for which a seat is appropriate.

Regarding the understanding of the user, was founded that the users involved in the "low birth weight infant" transportation include three distinct groups of people: (1) the "low birth weight infants"; (2) the healthcare members, which interact with the infant in the hospital; and (3) the family members.

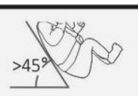
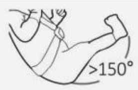
By observing infant transportation, the designer found that the infants are currently transported either in private cars with "child restraint devices" as in collective vehicles in the arms of caregivers. Among the common issues with the use of "child restraint devices" were: seat inclination larger than 45 degrees, abnormal curvature of the spine in relation to frontal plane, inappropriate flexion of the head. When caregivers do not put additional support in the "child restraint devices", the infant discomfort was evident (Fig. 3). While, among the common issues in the collective vehicles in the arms of caregivers were (Fig. 4): hyperextended head of the child, neck flexion with chin on the chest and abnormal curvature of the spine in the frontal plane.

Figure 3. Infant discomfort in a "child restraint device"

Figure 4. Infant in the arms of the caregiver

The analyzed issues in the transport of “low birth weight infants” were collected in the Tab. 1 and Tab. 2, in these each problem received a value and its occurrence, then the problem occurrence and importance were multiplied obtaining a risk value. Finally, the risk values were summed obtaining a detriment index of comfort and safety, which was 508 in “child restraint devices” and 153 in “arms of caregivers”. These indexes were calculated to compare with indexes calculated in the Phase 4, after the use of the developed solutions.

Table 1. Review of the problems in “child restraint devices” (Cachopo and Arruda, 2015)

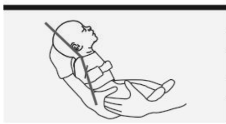
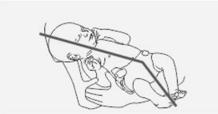
Problem ou issue	Rated			Rated		
	Occurrence (O)	Importance (G)	Risk (R)	Occurrence (O)	Importance (G)	Risk (R)
 >45°	~~1~~ ~~2~~ ~~3~~ ~~4~~ ~~5~~	9	45	~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~	9	45
	1 ~~2~~ ~~3~~ ~~4~~ ~~5~~	5	20	6 ~~7~~ 8 ~~9~~ ~~10~~	5	15
 >150°	1 2 3 4 5	5	0	6 7 8 9 10	5	0
 >0°	~~1~~ ~~2~~ ~~3~~ 4 ~~5~~	10	40	~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~	10	50
	1 ~~2~~ ~~3~~ ~~4~~ ~~5~~	8	32	~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~	8	40
	1 2 3 4 5	6	0	6 7 8 9 10	6	0
	1 2 3 4 5	3	0	6 7 8 9 10	3	0
	~~1~~ ~~2~~ ~~3~~ ~~4~~ ~~5~~	9	45	~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~	9	45
	~~1~~ ~~2~~ ~~3~~ ~~4~~ ~~5~~	8	40	~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~	8	40
	1 2 ~~3~~ ~~4~~ 5	7	14	6 7 8 ~~9~~ 10	7	7
	1 ~~2~~ 3 ~~4~~ ~~5~~	10	30	6 7 8 9 10	10	0

Index table:

INDEX (OXG)	RISK PRIORITY (R)
<21	Low (acceptable risk)
>20 e <26	Medium (unacceptable risk)
>26	High (unacceptable risk)

INDEX Σ(OXG)	TOTAL DETRIMENT OF COMFORT AND SAFETY
508	In the child restraint device

Table 2. Review of the problems in "arms of caregivers" (Cachopo and Arruda, 2015)

Problem ou issue	Rated: Occurrence (O)	Rated: Importance (G)	Rated: Risk (R)
	1X 2 3X 4 5X	9	27
	1X 2 3X 4X 5X	10	40
	1 2 3 4X 5	7	7
	1 2 3X 4 5X	5	15
	1 2 3 4 5X	6	6
	1 2 3 4X 5	8	8
	1x 2x 3x 4x 5x	10	50

Index table:

INDEX (OXG)	RISK PRIORITY (R)
<21	Low (acceptable risk)
>20 e <26	Medium (unacceptable risk)
>26	High (unacceptable risk)

INDEX Σ(OXG)	TOTAL DETRIMENT OF COMFORT AND SAFETY
153 (Colocar valor aqui)	In the arms

User tasks were identified both for the transport in private cars with "child restraint devices" and for collective vehicles in the arms of caregivers. Examples of the tasks in the transport with use of "child restraint device"include: placing infant on the "child restraint devices", seat belts adjustment, locking seat belts, infant transport, unlocking seat belts and carrying infant.

Each type of studied transport (in private cars with "child restraint devices" and in collective vehicles in the arms of caregivers), is characterized by differences in ambient light, noise levels, people density, infant risk levels and stress levels for caregivers. Although private cars can better support the security in the transport and offer greater comfort to caregivers, in this type of transport there is a high risk to the child that is related with of low usability levels of "child restraint devices" in "low birth weight infants".

The information collected in Phase 1 served to identify a series of needs used to specify requirements that should followed in the development of the solutions.

3.2 Phase 3

Each of the first two process phases served to direct the designs through requirements. These designs were iteratively revised and refined. Ideas, design concepts, and design alternatives resulted to project final solutions. A group of ideas for transport with use of "child restraint device" and other ideas group for collective transport resulted (Fig. 5 and Fig. 6). A group of concepts for transport with use of "child restraint devices" and a group for collective transport resulted (Fig. 5 and Fig. 6). Finally, three alternatives for transport with use of "child restraint devices" and three for collective transport resulted (Fig.7 and Fig.8) and one finish design or final solution for transport with use of "child restraint devices" and one for collective transport resulted.

Figure 5. Ideas for transport with use of “child restraint devices” (Cachopo and Arruda, 2015)

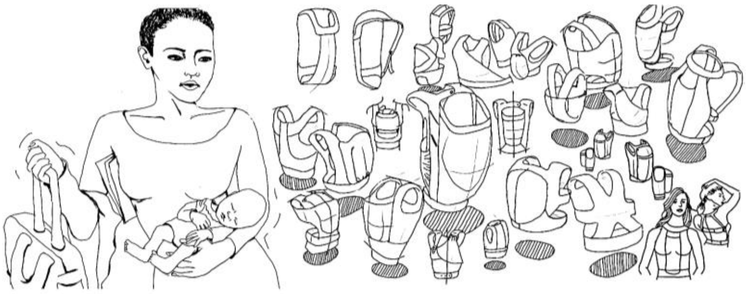


Figure 6. Ideas for collective transport (Cachopo and Arruda, 2015)

Figure 7. Concepts for transport with use of “child restraint devices” (Cachopo and Arruda, 2015)

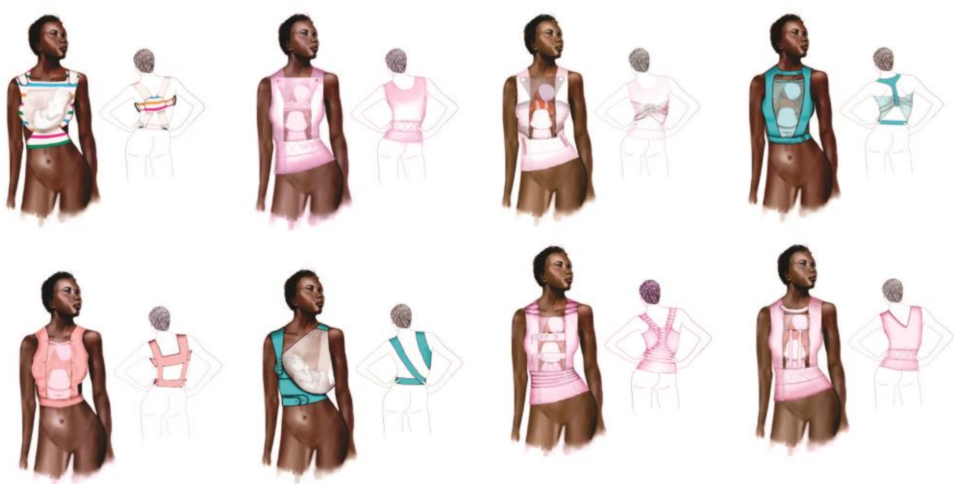


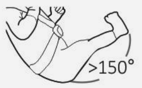
Figure 8. Concepts for collective transport (Cachopo and Arruda, 2015)

3.3 Phase 4

The analyzed issues in the transport of “low birth weight infants” with the use of the developed solutions were collected in the Tab. 3 and Tab. 4, in these each problem received a value and its occurrence, then the problem occurrence and importance were multiplied obtaining a risk value. Finally, the risk values were summed obtaining a detriment index of comfort and safety, which was 0 in “child restraint devices” and 18 in “arms of caregivers”, comparing with the index of the Phase 4, 508 in “child restraint devices” and 153 in “arms of caregivers”, the improve in the transport of “low birth weight infants” is evident.

The results of the satisfaction questionnaire were an percentage of user satisfaction equal to 97,3% with the solution for usage in particular vehicles and 95.3% with the solution for usage in collective vehicles.

Table 1. Review of the problems in “child restraint devices” with use of the developed solution (Cachopo and Arruda, 2015)

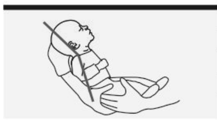
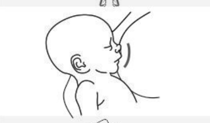
Problem ou issue	Rated			Rated		
	Occurrence (O)	Importance (G)	Risk (R)	Occurrence (O)	Importance (G)	Risk (R)
	1 2 3 4 5	9	0	6 7 8 9 10	9	0
	1 2 3 4 5	5	0	6 7 8 9 10	5	0
	1 2 3 4 5	5	0	6 7 8 9 10	5	0
	1 2 3 4 5	10	0	6 7 8 9 10	10	0
	1 2 3 4 5	8	0	6 7 8 9 10	8	0
	1 2 3 4 5	6	0	6 7 8 9 10	6	0
	1 2 3 4 5	3	0	6 7 8 9 10	3	0
	1 2 3 4 5	9	0	6 7 8 9 10	9	0
	1 2 3 4 5	8	0	6 7 8 9 10	8	0
	1 2 3 4 5	7	0	6 7 8 9 10	7	0
	1 2 3 4 5	10	0	6 7 8 9 10	10	0

Index table:

INDEX (OXG)	RISK PRIORITY (R)
<21	Low (acceptable risk)
>20 e <26	Medium (unacceptable risk)
>26	High (unacceptable risk)

INDEX Σ(OXG)	TOTAL DETRIMENT OF COMFORT AND SAFETY
Colocar valor aquí 0	In the child restraint device

Table 2. Review of the problems in "arms of caregivers" with use of the developed solution (Cachopo and Arruda, 2015)

Problem ou issue	Rated		
	Occurrence (O)	Importance (G)	Risk (R)
	1 2 ~~3~~ 4 ~~5~~	9	18
	1 2 3 4 5	10	0
	1 2 3 4 5	7	0
	1 2 3 4 5	5	0
	1 2 3 4 5	6	0
	1 2 3 4 5	8	0
	1 2 3 4 5	10	0

Index table:

INDEX (OXG)	RISK PRIORITY (R)
<21	Low (acceptable risk)
>20 e <26	Medium (unacceptable risk)
>26	High (unacceptable risk)

INDEX Σ(OXG)	TOTAL DETRIMENT OF COMFORT AND SAFETY
18	In the arms

4. CONCLUSION

This report details a design approach conducted to development two solutions to "low birth weight infants" transportation. This approach emphasized an understanding of the needs of the different user groups and the current conditions of the problem in question.

The findings entail that it is important to include the different user groups throughout the design process in order to get hold of the knowledge of the problem context, which can to include anthropometric, anatomical and biomechanical characteristics of the users. When the characteristics of the users are not considered, there is a low possibility to solve correctly a design or engineering human-centered problem. Evidence of this is that the "low birth weight infants" transport has not changed significantly for many years, preliminary evidence suggests that the same problems of several years exist. In this context, the approach proposed here, can be a promising guide for the development of human-centered projects that seek to improve the conditions of life.

The existing "child restraint devices" on the market do not appear to meet the needs of "low birth weight infants", these devices frequently present high inclination and can be longer than the necessary for these children.

The developed solutions maintain in the children a correct ergonomics posture and more comfortable and safe relative to existing solutions.

The users show high levels of satisfaction in relation to the developed solutions.

The human-centered design appear to show levels of affectivity to conduct the development of human-centered projects, especially projects directed to a vulnerable or minority group of the population, which usually present special needs.

5. ACKNOWLEDGEMENTS

There is gratitude to participants of the design process that contributed with valuable ideas, suggestions and information. Thanks to the healthcare professionals that assisted and contributed during conducting the process. Finally, authors are thankful to CAISM for collaboration in the process development and to CAPES for be funding source during the research.

6. REFERENCES

Abras, C., Maloney-Krichmar, D. and Preece, J., 2004. "*User-Centered Design. W. Encyclopedia of Human-Computer Interaction*". Sage Publications, Thousand Oaks.

ABNT, 2009. "*NBR 14400: Veículos rodoviários automotores - Dispositivos de retenção para crianças - Requisitos de segurança*". ABNT, Rio de Janeiro.

Bull, M. J. and Stroup, K. B., 1985. "Premature infants in car seats". *Pediatrics*, Indianapolis, Vol. 20, p. 336–9

Cachopo, C.J.R. and Arruda, A. C. F., 2015. *Devices for transport of "low birth weight infants": a human centred design approach*. MSc. dissertation, University of Campinas, Campinas.

CONTRAN, 2008. "*Resolução no 277 de 28 de maio de 2008: Dispõe sobre o transporte de menores de 10 anos e a utilização do dispositivo de retenção para o transporte de crianças em veículos*". CONTRAN, Brazil.

Côté, A., Bairam, A., Deschenes, M. and Hatzakis, G., 2008. "Sudden infant deaths in sitting devices". *Arch Dis Child*, Montreal, Vol. 93, p. 384–389.

Joffe, N. and Hall, J., 2006. "Limiting the risks of apnoea and bradycardia in low birth weight infants using car seats". *Journal of Neonatal Nursing*, Vol. 12, p. 91–96.

Macaulay, L. A., 1996. "*Requirements Engineering*". Springer Science & Business Media, London.

Nielsen, J., 2012. "*How Many Test Users in a Usability Study?*" NN/g Nielsen Norman Group. 19 Aug. 2014 <http://www.nngroup.com/articles/how-many-testusers/>.

Ullman, D., 2009. "*The Mechanical Design Process*". McGraw-Hill, New York, 4a edition.

UNICEF Brasil, 2013. "*A situação da prematuridade no Brasil*". UNICEF Brasil. 4 Nov. 2014 <http://www.unicef.org/brazil/pt/media_25849.htm>.

Waiselfisz, J. J., 2014. "*Mapa da Violência 2014. Os jovens do Brasil*". FLACSO, Rio de Janeiro.

Willett, L. D., Leuschen, M. P.; Nelson, L. S.; Nelson, R. M., 1986. "Risk of hypoventilation in premature infants in car seats". *The Journal of Pediatrics*. Vol. 109, n. p. 245–248.

7. RESPONSIBILITY NOTICE

Cindy Janneth Rondón Cachopo and Antonio Celso Fonseca de Arruda are the only responsible for the printed material included in this paper.