



The development and validation of an ergonomics index for assessing tractor operator work place

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ABSTRACT: *This study aimed to develop and validate an ergonomics index for the operator workplace assessment of agricultural tractors sold in the Brazilian market. To develop the ergonomics index, the operator work places were assessed for compliance with current, national and international, safety and ergonomics standards. The following standards were analyzed to develop ergonomics index: ISO 15077 (1996), which regulates the position of operator controls; ABNT NBR ISO 4254-1(2015) and ABNT NBR ISO 4252 (2011), which regulate the access to operator workplaces; and NR 12 (2010), which determines the mandatory items of operator workplaces. Thirty-four operator work places of 152 models of new agricultural tractors sold in the Brazilian market were analyzed in this study. Ergonomics index was developed and validated using these standards, and the findings enabled the ranking of agricultural tractors. Therefore, the proposed ergonomics index proved feasible and may be applied to other agricultural machines.*

Key words: ergonomics, safety, operator controls, access, standards.

Criação e validação de índice ergonômico para avaliação de postos de operação de tratores agrícolas

RESUMO: *Objetivou-se com este trabalho criar e validar um índice ergonômico capaz de qualificar os postos de operação de tratores agrícolas comercializados no mercado brasileiro. Para a composição do índice ergonômico, os postos de operação foram avaliados quanto ao atendimento às normas vigentes, nacionais e internacionais, de segurança e de ergonomia. As seguintes normas foram levadas em consideração para a criação do índice ergonômico: ISO 15077 (1996) - determina o posicionamento dos órgãos de comando; ABNT NBR ISO 4254-1 (2015) e ABNT NBR ISO 4252 (2011) - referem-se à acessibilidade aos postos de operação; e NR 12 (2010) - determina a presença de itens obrigatórios nos postos de operação. Fizeram parte desta análise 34 postos de operação, que são montados em 152 modelos de tratores agrícolas novos, comercializados no mercado brasileiro. Com o auxílio dessas normas o índice ergonômico foi desenvolvido e validado usando esses padrões, e os resultados permitiram ranquear os tratores agrícolas. Conclui-se que o índice ergonômico proposto se mostrou eficiente quanto à exequibilidade e pode ser aplicado em outras máquinas agrícolas.*

Palavras-chave: ergonomia, segurança, comandos de operação, acessibilidade, normativas.

INTRODUCTION

In modern agriculture, the agricultural tractor is crucial for various farming activities. According to ROZIN (2004), the tractor has been regarded as the driving force for the Brazilian agricultural development owing to its versatility in performing numerous tasks in rural environments and is the source of power and traction for several agricultural machines and implements.

Ergonomics approach tends to develop operator work places that reduce the biomechanical

and cognitive constraints and help the operators to maintain an adequate work posture (IIDA, 2005). SCHLOSSER et al. (2002a) stress the importance of operators reaching and activating operator controls with minimum effort, and maintaining appropriate body posture.

An ergonomic operator work place design must ensure adequate work station space for any operator, regardless of his or her physical structure, to adopt comfortable work postures and for personal belongings (FERNANDES et al., 2010). Agricultural modernization has led to significant improvement

in the operator work places of Brazilian tractors by encouraging the application of ergonomic methods (FRANCHINI, 2007); however, many requirements remain unfulfilled (NIETIEDT et al., 2012).

The position and characteristics of tractor access platforms may cause numerous accidents, especially in the absence of properly designed hand holds and handrails for tractor mounting and dismounting (SCHLOSSER et al., 2002b). Access platforms having adequate size, space, and safety can contribute to decreasing risk exposure, thereby decreasing the number of work accidents (MATTAR et al., 2010).

With the objective of evaluating the safety and ergonomics levels of operator work places agricultural machinery, CASALI et al. (2011) assessed the position of the main controls of self-propelled sprayers. The authors concluded that ignition switches are commonly located within the comfort zone of seated operators in sprayers with multifunctional controls.

To analyze the compliance with the standard regulating the position of hand and foot controls, ROZIN et al. (2010) assessed 35 tractor operator work places based on ABNT NBR ISO 4253 (1999) recommendations. The authors concluded that the clutch and accelerator pedals were the items that best and worst met the standard, respectively.

NIETIEDT et al. (2012) analyzed the position of operator controls in four new agricultural tractors with 55kW (75cv) nominal power, and concluded that frequently used controls were most commonly reported in the comfort zone of the Valtra tractor, model A750. DEBIASI et al. (2004) evaluated agricultural tractors used in the Central region of Rio Grande do Sul, and concluded that these tractors have several ergonomics and safety limitations.

Various indices have been developed by researchers to assess and classify agricultural tractors based on the safety and ergonomics characteristics of operator work places. In this regard, ROZIN (2004) proposed an index divided into three plots: the first referred to operator controls, the second referred to the access platform and the third considered the general characteristics of the operator work place.

In line with ROZIN (2004), this study aims to develop an Operator Work place Ergonomics Index (OWEI) to assess the compliance with operator work place standards of new agricultural tractors sold in the Brazilian market, to validate this index according to specifications recommended by safety and ergonomics standards and, finally, to rank operator work places based on the proposed index.

MATERIALS AND METHODS

The OWEI was developed considering the Brazilian and international safety and ergonomics standards, including the ABNT NBR ISO 4252 (2011) and NR 12 (2010) standards, and those previously used by ROZIN (2004), namely, the ISO 17077 (1996) and ABNT NBR ISO 4254-1 (2015) standards used for the Seat Index Point.

Each operator work place was scored as a function of compliance with the standards used. The scoring method was based on the Index Number (IN) theory and totaled one (01). The IN is a value that expresses an amount in comparison to a reference quantity, that is, relative values (ENDO, 1986). In this study, the baseline/reference was taken as 100. Thus, the behavior of the variables was analyzed (Table 1) regarding compliance with the standards.

The ISO 15077 (1996) standard regulates the position of operator controls and their location within the comfort zones of seated operators. Of all controls that may be found in an operator work place, 22 were assessed in cab tractors and 21 in cables tractors (Table 2).

The points assessed were plotted in three Cartesian axes (x, y, z) to establish the Vertical Longitudinal (VLP) and Upper Horizontal (UHP) profiles of operator work places. In the OWEI development, the ISO 15077 (1996) standard received the maximum score, 0.45, because this standard regulates ergonomics issues and the position, access to, and handling of controls, whose poor position may cause physical and mental fatigue among agricultural machinery operators, in addition to occupational diseases caused by repetitive movements (ROZIN, 2010).

Regarding safety and access to operator work place, the ABNT NBR ISO 4254-1 (2015) standard received a score of 0.25 because this standard regulates access steps and their number and size, and the presence and number of hand holds in both sides of the tractor.

The ABNT NBR ISO 4252 (2011) standard was used to assess the operator work place. This standard regulates tractor mounting and dismounting and the internal space of operator work places. Number and location of emergency exits and the dimensions of the internal free space of operator work places of agricultural tractors were analyzed according to this standard. Full compliance with this standard received a maximum score of 0.20 in the OWEI index because this standard regulates safety items, and their correct scaling in designing agricultural tractors decreases the risk of work accidents.

Table 1 - Contribution of each standard to the Operator Work place Ergonomics Index (OWEI) of agricultural tractors sold in the Brazilian market in 2016.

Operator work place ergonomics index (OWEI)	Score
Compliance with the ISO 15077 (1996) standard	0.45
21 controls	0.02
Compliance with the ABNT NBR ISO 4254-1 (2015) standard	0.25
Distance between steps	0.027
Height from the first step to the ground	0.027
Depth	0.027
Vertical distance to the threshold	0.027
Clearance	0.027
Vertical distance to the ground	0.027
Minimum width	0.027
Maximum width	0.027
Vertical stops on both sides	0.027
Non-skid surface	0.027
Compliance with the ABNT NBR ISO 4252 (2011) standard	0.20
Emergency exits	0.025
Mounting clearance	0.025
Longitudinal clearance at 750-mm height	0.025
Longitudinal clearance at 1000-mm height	0.025
Longitudinal clearance at 1250-mm height	0.025
Distance to the ceiling surface of the cab	0.025
Lateral space	0.025
Distance from the steering wheel to the cab surface	0.025
Compliance with the NR 12 (2010)	0.10
Ignition key or locking device	0.006
Protection at the bottom of the steps	0.006
Position Taillights	0.006
Back-up beeper	0.006
Rear view mirror	0.006
Top protection structure – TPS	0.006
Seat belt	0.006
Manual available at the operator work place	0.006
Safe, weather proof, and corrosion resistant	0.006
Steering wheel is not considered a handhold	0.006
Tires, hubs, wheels, and fenders considered steps	0.006
Has handholds on both sides of the tractor	0.006
Three-point mount and dismount	0.006
Handle with a minimum length of 150mm	0.006
Slope of the ladder meets the standard requirements	0.006
Preventing the accumulation of water and dirt	0.006
Total	1.00

To assess the presence of mandatory safety items in operator work places, NR 12 (2010), which defines technical references, fundamental principles, and protection measures that must be observed in the work environment, was applied setting the maximum score at 0.10. NR 12 (2010) received a lower score than the other standards because several safety and

ergonomics items regulated by this standard are included in the other standards used in this study. Compliance with the following items was analyzed: ignition switch, taillight, horn and access platform steps, and surface.

To validate the OWEI, 34 operator work places of 152 new agricultural tractor models sold

Table 2 - Nomenclature used to classify the operator work places of agricultural tractors sampled in the main dealers of the Central region of Rio Grande do Sul in 2016.

	500	1AA	Cabless
Agrale	5000	2AP	Cabless
		2AC	Cab
	6000	3AP	Cabless
Case-IH		3AC	Cab
	FARMAL	1CP	Cabless
		1CC	Cab
		2CP	Cabless
	PUMA	3CC	Cab
	MAGNUM	4CC	Cab
John Deere	5E	2JC	Cab
		2JP	Cabless
		1JS	Cabless
	6J	3JC	Cab
LS Tractor	7J	4JC	Cab
	PLUS	1LP	Cab
		1LC	Cabless
	U	2LP	Cabless
		2LC	Cab
		1MP	Cabless
Massey Ferguson	4200	1MC	Cab
	7100	3MP	Cabless
		3MC	Cab
	7000	4MC	Cab
	6000	2MC	Cab
New Holland	TL	1NP	Cabless
		1NC	Cab
	SÉRIE 30	2NA	Cabless
	T6	3NC	Cab
	T7	4NC	Cab
Valtra	A	1VP	Cabless
	BM	2VC	Cab
	BH	3VC	Cab
	BT	4VC	Cab

in the Brazilian market were assessed. Data were collected through ergonomics assessments performed at the main agricultural machinery concessionaires of the Central Depression region of Rio Grande do Sul. An agricultural tractor must meet all safety and ergonomics standards imposed by the current legislation in force to receive the maximum score (OWEI = 1.00).

The sample consisted of tractors with 4x2 and 4x2 wheels, auxiliary front wheel drive (FWD), 36.7kW (50cv) nominal power, rear axle track higher than 1280mm, and 600kg minimum mass. Tractors were grouped using the classification proposed by FARIAS et al. (2016). This grouping also considered homogeneous

operator work places, and identified the work places according to the following parameters: operator work place type (conventional, with a semi-platform, or with an access platform), and version (cab and cabless).

The nomenclature of operator work places consists of three alphanumeric characters. The first character is an integer corresponding to the commercial line or serial number of the tractor, the second one corresponds to the first letter of the brand of the tractor, and the third one refers to the type of operator work place, where in cabless operator work places, operator work places with a semi-platform, cabless operator work places with an access platform, and cab operator work places are labeled A, S, P, and C, respectively (Table 2).

Operator work places of agricultural tractors of the main companies operating in the Brazilian market, found in dealers of the Central region of Rio Grande do Sul and sold in 2016, were sampled. They were identified by the following brand names: Agrale, Case-IH, John Deere, LS Tractor, Massey Ferguson, New Holland, and Valtra. The ergonomics and safety characteristics of agricultural tractors established as standard by the manufacturer were analyzed.

RESULTS AND DISCUSSION

Regarding the compliance with the ISO 15077 (1996) standard, the operator work place with the highest number of controls located in comfort zones advocated by the standard was 4CC, scoring 0.332, and the work place with the lowest score was 2NA, scoring 0.156 for a total score of 0.45.

The operator work places 1AA, 2AP, 2AC, 3AP, and 3AC lacked steps with nonslip characteristics, failing to meet the ABNT NBR ISO 4254-1 (2015) standard, and scored zero. Conversely, in 84.84% operator work places, the steps have a nonslip surface but lack side steps at least in one of the access steps, failing to meet the standard recommendation and received a score of 0.013.

Regarding the height from the first step to the ground, used to mount and dismount the tractor, 95.24% cabless tractors assessed met the ABNT NBR ISO 4254-1 (2015) standard, whereas the operator work places of cab tractors showed 100% compliance and received the highest score (0.027). This result is in contrast with MATTAR et al. (2010), who reported that the height from the first step to the ground of 70.43% tractors assessed was lower than or equal to that specified by the standard.

The analysis of step depth compliance with the ABNT NBR ISO 4254-1 (2015) standard showed that operator work places of cabless tractors had only 45.24% compliance and those of cab tractors had 77.78% compliance. MATTAR et al. (2010) assessed tractor step length, and concluded that 61.90% tractors met the standard requirements; this value is similar to that reported in the present study (61.51%).

Regarding the vertical distance from the last step to the cab threshold, all tractors with a multi-step frame met the ABNT NBR ISO 4254-1 (2015) standard, receiving the maximum score in this item, and the analysis of tractor step width showed that the number of operator work places of cabless tractors was higher than that of cab tractors (22.22%). Only 14 of the 34 operator work places received the

maximum score (0.25) regarding the compliance with the ABNT NBR ISO 4254-1 (2015) standard.

The analysis of the number of emergency exits based on the ABNT NBR ISO 4252 (2011) standard, which requires at least two, showed that all cab tractors showed 100% compliance, receiving the maximum score of 0.025. In all cases, the exits were found at the left door and the rear window of the cab. However, regarding the distance from the seat to the ceiling of the cab, six operator work places (2AC, 1MC, 3MP, 1LC, 3JC, and 4JC) scored zero. Another item assessed, which was not met in three operator work places (4MC, 2VC, and 4VC), was the distance from the steering wheel to the cab surface. This may be explained by the control positioned next to the steering wheel.

The analysis of cabin door size showed that all 34 operator work places comply with the standards, when assessing the longitudinal clearance at the largest width and the entry clearance measurements recommended by the ABNT NBR ISO 4252 (2011) standard possibly because the tractor door is considered as an emergency exit in case of accidents.

Analyzing the slope of the steps according to the NR 12 (2010) standard, the tractor steps are not visible to the operator when dismounting in 57.78% operator work places. According to ROZIN (2004), the lack of visibility of tractor steps may lead operators to jump, increasing the likelihood of an accident. In a research study conducted among operators of the Central region of the state of Rio Grande do Sul, DEBIASI et al. (2004) consider the dismounting structure of some operator work places of agricultural tractors inadequate and unsafe.

Regarding the presence of mandatory items, seven operator work places (3CC, 4CC, 3JC, 4JC, 2MC, 4MC, and 4VC), met 100% safety recommendations established by the NR 12 (2010) standard and received the maximum score (0.1). The 3AP operator work place had the lowest compliance and scored 0.081.

Table 3 outlines the operator work places assessed and ranked in decreasing order, that is, from the highest to lowest OWEI, considering the compliance with the items assessed in relation to the standards. As outlined in table 3, the 4CC operator work place, Case-IH brand, had the highest ergonomics index of all operator work places analyzed (0.8912). The lowest OWEI was reported in the 2NA operator work place, New Holland brand (0.7173). The mean OWEI was 0.8026, and 48.48% operator work places ranked higher than the mean OWEI.

Table 3 - Operator Workplace Ergonomics Index (OWEI) ranking of operator work (OW) place of agricultural tractors assessed and sold in 2016.

Ranking	OW	Manufacturer	OWEI
1	4CC	Case-IH	0.8912
2	2MC	Massey Ferguson	0.8565
2	3VC	Valtra	0.8462
2	3CC	Case-IH	0.8416
5	2JC	John Deere	0.8404
6	3NC	New Holland	0.8404
7	4VC	Valtra	0.8354
8	4MC	Massey Ferguson	0.8354
9	1MC	Massey Ferguson	0.8341
10	3MP	Massey Ferguson	0.8330
11	4NC	New Holland	0.8246
12	1NP	New Holland	0.8200
13	1NC	New Holland	0.8143
14	1AP	Agrale	0.8141
15	1CC	Case-IH	0.8128
16	3JC	John Deere	0.8067
17	2LP	LS Tractor	0.8057
18	4JC	John Deere	0.8023
19	1MP	Massey Ferguson	0.8012
20	1CP	Case-IH	0.8010
21	1JP	John Deere	0.7895
22	2CP	Case-IH	0.7882
23	3AC	Agrale	0.7825
24	2JP	John Deere	0.7809
25	2LC	LS Tractor	0.7796
26	2AC	Agrale	0.7775
27	2VC	Valtra	0.7775
28	1LC	LS Tractor	0.7739
29	1VP	Valtra	0.7693
30	3AP	Agrale	0.7564
31	1LP	LS Tractor	0.7546
32	3MC	Massey Ferguson	0.7516
33	2AP	Agrale	0.7443
34	2NA	New Holland	0.7173
Coefficient of Variation (%)			4.53

Because the safety and ergonomics standards of agricultural tractors assessed in this study are in force in Brazil, manufacturers should fully comply with these standards, which would mean a 1.0 OWEI. However, the findings suggested that all tractors fail to comply with Brazilian and international standards.

CONCLUSION

This study proposed an ergonomics index for the operator work place assessment of agricultural

tractors sold in the Brazilian market. The proposed ergonomics index (OWEI) proved feasible and improved the assessment of safety and ergonomics characteristics of operator work places of agricultural tractors.

Based on the proposed score, tractors were ranked using the OWEI. However, no tractor fully met the safety and ergonomics standards.

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REFERENCES

- ABNT. (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS). **ABNT NBR ISO 4252**: tratores agrícolas: local de trabalho do operador, acesso e saída: dimensões. Rio de Janeiro, 2011. 6p.
- ABNT. (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS). **ABNT NBR ISO 4254-1**: máquinas agrícolas - segurança parte 1: requisitos gerais. Rio de Janeiro, 2015. 48p.
- BRASIL. Ministério do Trabalho e Emprego. **Norma Regulamentadora Nº 12**. 2010. Available from: <[http://portal.mte.gov.br/data/files/8A7C816A4295EFDF0142FC261E820E2C/NR-12%20\(atualizada%202013\)%20III%20-%20\(sem%2030%20meses\).pdf](http://portal.mte.gov.br/data/files/8A7C816A4295EFDF0142FC261E820E2C/NR-12%20(atualizada%202013)%20III%20-%20(sem%2030%20meses).pdf)>. Accessed: Mar. 29, 2017.
- CASALI, A.L. et al. Conformance of operating post of self-propelled sprayers. **Engenharia na Agricultura**, Viçosa, v.19, n.6, p.548-556, 2011. Available from: <<http://dx.doi.org/10.13083/1414-3984.v19n06a07>>. Accessed: Feb.17, 2017. doi: 10.13083/1414-3984.v19n06a07.
- DEBIASI, H. et al. Ergonomic characteristics of agricultural tractors used in central region of Rio Grande do Sul State, Brazil. **Ciência Rural**, Santa Maria, v.34, n.6, p.1807-1811, 2004. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782004000600021&lng=en&nrm=iso&tlng=pt>. Accessed: Feb. 16, 2017. doi: 10.1590/S0103-84782004000600021.
- ENDO, S.K. **Números índices**. 1.ed. São Paulo: Atual, 1986. 74p.
- FARIAS, M.S. et al. Evaluation of new agricultural tractors engines by using a portable dynamometer. **Ciência Rural**, Santa Maria, v.46, n.5, p.820-824, 2016. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782016000500820>. Accessed: Feb. 16, 2017. doi: 10.1590/0103-8478cr20150406.
- FERNANDES, H.C. et al. Ergonomic evaluation of the operator cabin of a forest tractor. **Revista Ceres**, Viçosa, v.57, n.3, p.307-314, 2010. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0034-737X2010000300004>. Accessed: Feb. 12, 2017. doi: 10.1590/S0034-737X2010000300004.
- FRANCHINI, D. **Análise do nível de vibrações verticais no assento de um trator agrícola**. 2007. 139p. Dissertação (Mestrado em Engenharia Agrícola) - Universidade Federal de Santa Maria, Santa Maria, 2007.

IIDA, I. **Ergonomia: projeto e produção**. 2. ed. São Paulo: Ed. Edgard Blücher, 2005. 465p.

ISO. (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION). **ISO 15077**: tractors and machinery for agriculture and forestry: operator controls: actuating forces, their displacement and location. Genève, 1996. 14p.

MATTAR, D.P et. al. Conformity of the accesses and exits of agricultural tractors workplaces according to NBR/ISO 4252 standard. **Engenharia Agrícola**, Jaboticabal, v.30, n. 1, p.74-81, 2010. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-69162010000100008&lng=en&nrm=iso&tlng=pt>. Accessed: Feb. 12, 2017. doi: 10.1590/S0100-69162010000100008.

NIETIEDT G.H. et al. Distribution of operation controls in national agricultural tractors with 55 kW of power. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.16, n.6, p.690-695, 2012. Available from: <<http://www.scielo.br/pdf/rbeaa/v16n6/v16n06a15.pdf>>. Accessed: Feb. 20, 2017. doi: 10.1590/S1415-43662012000600015.

ROZIN, D. **Conformidade do posto de operação de tratores agrícolas nacionais com normas de ergonomia e segurança**. 2004, 187p. Dissertação (Mestrado em Engenharia Agrícola) - Universidade Federal de Santa Maria, Santa Maria, 2004.

ROZIN, D. et al. Compliance of the command operations of national agricultural tractors with the NBR ISO 4253 standard. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.14, p.1014-1019, 2010. Available from: <<http://dx.doi.org/10.1590/S1415-43662010000900015>>. Accessed: Feb. 16, 2017. doi: 10.1590/S1415-43662010000900015.

SCHLOSSER, J.F et al. Characterization of the accidents involving agricultural tractors. **Ciência Rural**, Santa Maria, v.32, n.06, p.45-52, 2002 (a). Available from: <<http://dx.doi.org/10.1590/S0103-84782002000600010>>. Accessed: Feb. 16, 2017. doi: 10.1590/S0103-84782002000600010.

SCHLOSSER, J.F. et al. Anthropometrics applied to the agricultural tractors operators. **Ciência Rural**, Santa Maria, v.32, n.06, p.61-72, 2002 (b). Available from: <<http://dx.doi.org/10.1590/S0103-84782002000600011>>. Accessed: Feb. 15, 2017. doi: 10.1590/S0103-84782002000600010.