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ORIGINAL ARTICLE

The effect of different supermarket checkout workstations on trunk kinematics of checkout operators

O efeito de diferentes modelos de checkout na cinemática de operadores de supermercado

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Abstract

Objectives: This study analyzed the effect of a standard and a modified checkout workstation during a simulated task on trunk postures of a supermarket checkout operator. **Methods:** Eight participants performed a task involving grasping, scanning and depositing products, while 3D images of the trunk were collected. **Results:** A number of kinematic changes were observed in trunk posture. A greater anterior flexion (3.0±1.2º) and lateral bending during grasping (7.1±1.4º) were found in the standard checkout workstation when compared to the modified model ($p<0.05$). Other variables did not show significant differences ($p>0.05$). **Discussion:** The modified checkout workstation provided less lateral bending of the trunk to grasp products (8.1º ± 2.8; $p<0.05$), which was considered an advantage with respect to the standard model. Changes in the sagittal and transversal planes were not observed ($p>0.05$), irrespective of the checkout workstations ($p>0.05$). The modified checkout workstation successfully reduced risk of injury in some aspects, particularly the problems associated with lateral bending of the trunk. Other studies are required to test whether such potential benefits are obtained on a daily basis. **Conclusions:** Supermarket checkout operators may be at high risk of occupational injury due to different workstation demands. Modifications to checkout workstation design are an attractive possibility to reduce postural stress and fatigue in checkout operators. Longitudinal studies are required to test whether changes observed in the present study are sustained in the long term.

Key words: supermarket checkout operators; supermarket checkout workstation; checkout workstation design; posture.

Resumo

Objetivos: Analisar o efeito de um modelo padrão e de um modificado de checkout durante uma tarefa simulada de um operador de caixa de supermercado. **Métodos:** Oito participantes desempenharam uma tarefa envolvendo apanhar, ler e depositar produtos, enquanto imagens 3D do tronco foram coletadas. **Resultados:** Um número de mudanças cinemáticas foram observadas na postura do tronco. Uma maior flexão anterior (3.0±1.2º) e uma inclinação lateral durante o apanhar (7.1±1.4º) foram encontradas no checkout padrão quando comparadas ao modelo modificado ($p<0.05$). Outras variáveis não apresentaram mudanças significativas ($p>0.05$). **Discussão:** O checkout modificado causou menor inclinação lateral do tronco para apanhar produtos (8.1º ± 2.8; $p<0.05$), o que foi considerado como uma vantagem em relação ao modelo padrão. Mudanças nos planos sagital transverso não foram observadas ($p>0.05$), independente do modelo do checkout ($p>0.05$). O modelo modificado se mostrou eficaz paras prover reduções de risco de lesão em alguns aspectos. Especificamente, problemas associados com as inclinações laterais do tronco podem ser reduzidos quando o checkout modificado é empregado. Outros estudos são necessários para testar se tais benefícios potenciais são obtidos em uso de base diária. **Conclusões:** Operadores de supermercado podem ter elevado risco de lesões ocupacionais devido a diferenças nas demandas de suas estações de trabalho. Modificações no design do checkout são uma possibilidade atrativa para reduzir o estresse postural ocupacional e a fadiga em operadores de checkout. Requerem-se estudos longitudinais para testar se as mudanças encontradas no presente estudo são sustentadas em longos períodos de uso.

Palavras-chave: operadores de supermercado; design do checkout, postura, caixa de supermercado.

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Introduction

The high incidence of cumulative trauma disorders in supermarket checkout operators is a growing problem that has been described by several studies[1,2]. The main risk factor associated with the development of cumulative trauma disorders is reported to be the prolonged exposure to repetitive bending/twisting movements at work[3]. Among several cumulative trauma disorders, back problems have been reported as the most frequent symptom among supermarket checkout operators[2,4,5] and may be associated with the large movements performed during the workday[6] and to ergonomic factors such as workstation design[7, 8, 9].

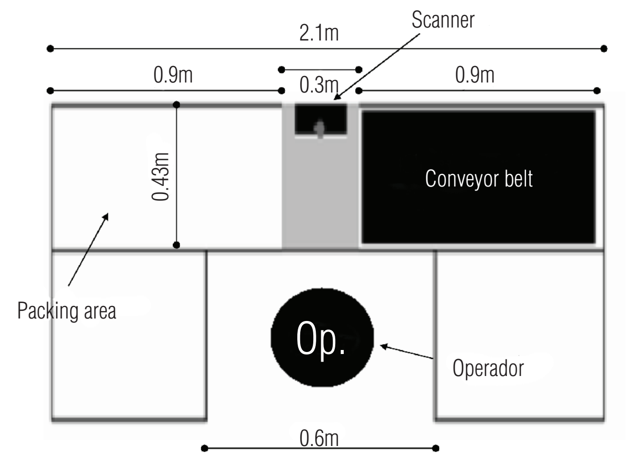
A recent study performed by our research group[6] analyzed a number of biomechanical variables of the trunk during a simulated task of supermarket checkout operators while handling products of different loads. We reported increased range of movement in the sagittal and frontal planes during handling of heavy products (up to 5 kg), which were accompanied by a large rotation of the trunk. Right side rotation of the trunk (when placing products in the packing area) was approximately four times greater than that performed to the left side (when grasping products from the end of the conveyor belt), irrespective of the products' weight. It has been suggested that other checkout workstations that allow operators to grasp and deposit products using a small range of motion may help to prevent a number of back problems that are likely to appear as a consequence of the postural deviations that are repeated on a daily basis. Activities combining flexion, lateral bending and rotation movements have been described as one of the main factors in the etiology of back problems[10]. Therefore, the use of other modified workstations may constitute a viable alternative to reduce the risk of back injuries among supermarket checkout operators.

Although some studies have proposed changes and suggested some desirable characteristics of the workstation as a way to reduce the risk of injury[11,12]. Others have indicated that changes in checkout workstation design, without modifying the methods of scanning, lifting and transferring objects, will only partially reduce the risk of injury[8,13]. In contrast, although the trunk is the most affected segment among checkout operators (60.0 - 77.0% of incidence)[4,13], no studies have performed a biomechanical analysis of the trunk to observe whether changes in checkout workstation design would help to reduce the occupational hazards of these operators. Therefore, this study aimed to determine the kinematics of the trunk during a simulated checkout task in which two checkout workstation designs were compared. The present study was limited to comparing the kinematics of the trunk using a standard and a modified checkout workstation. The modified checkout workstation was equipped with a continuous conveyor belt in conjunction with a detection system as an alternative to allow checkout operators to handle products near their mid-line and minimize the need for trunk movements. It is known that movement range and working posture are relevant factors in occupational safety as they contribute to loading and injury risk[14,15,16]. Furthermore, these factors are of interest to professionals involved in minimizing/preventing risks of injury in occupational settings such as physical therapists, ergonomists and designers. Therefore, this study aimed to quantify the influence of different design checkout workstations on the kinematics of the trunk in supermarket checkout operators. It was hypothesized that the modified checkout workstation is associated with smaller trunk motion when compared to the standard model.

Methods

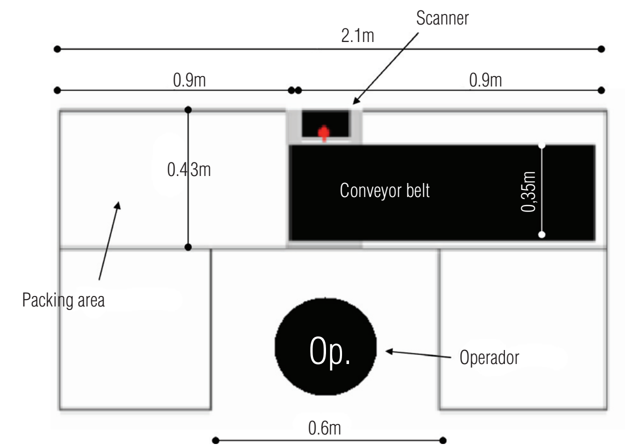
Eight healthy female participants (20.6±2.3 years; 1.63±0.06 m; 56.6±4.0 kg) with previous experience (10.1±2.6 months) as supermarket checkout operators were recruited from a supermarket close to the university and agreed to take part in this study. All participants received verbal explanation and gave their written informed consent to visit the laboratory for a single experimental session. All procedures were approved by the Ethics Committee (CEPE, number 0306) of Universidade Campos de Andrade (UNIANDRADE), Brazil. Participants were deemed sufficiently trained to produce consistent and representative movements performed during a workday because the actions required to perform the task were not very complex. No instructions about how to perform the task were given to the participants because they had previous experience. Participants were screened (i.e., asked by the researcher) for their history of back pain, known postural problems or other recurrent pain that would affect their performance. No participants were excluded due to back pain or postural problems.

The participants were asked to perform a complete cycle (grasping, scanning and depositing products of different weights) in a standard and in a modified checkout workstation. These experimental conditions followed a balanced order. The standard workstation was assembled with a conveyor belt, an optical scanner and a packing area as seen in Figure 1. The conveyor belt had an electronic sensor that activated and stopped the flow of products approximately 0.30 m from the checkout operators' mid-line in such a way that products were positioned diagonally – at approximately 45° to the right sagittal plane of the checkout operator. After manipulating and registering products in the optical scanner (positioned in front of them), products were manually deposited in the packing area. A number



Actual measurements are not in scale. Values are expressed in meters. The workstation height was 0.93 m.

Figure 1. Schematic representation of the standard checkout workstation.



Actual measurements are not in scale. Values are expressed in meters. The workstation height was 0.93 m.

Figure 2. Schematic representation of the modified checkout workstation.

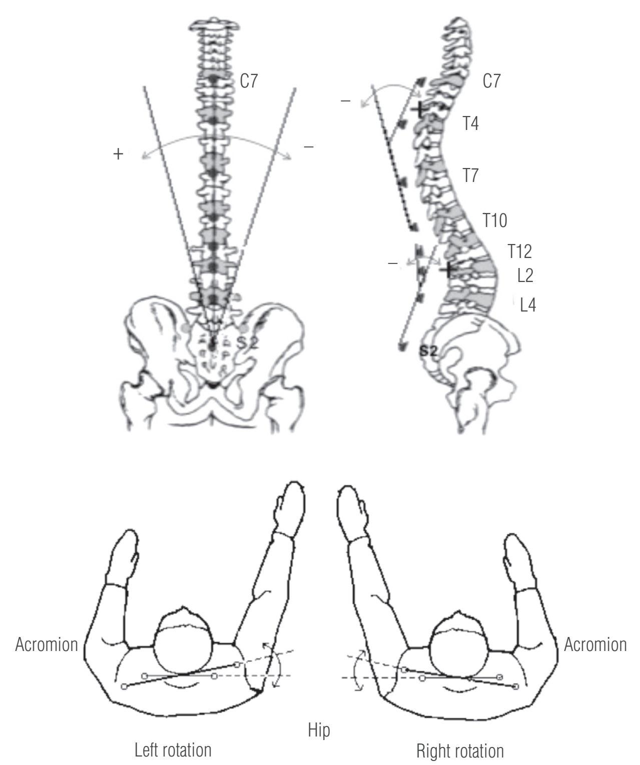
of modifications were made to the standard checkout workstation to obtain the modified workstation model. In the modified model, a continuous conveyor belt containing an electronic presence sensor stopped products in front of the checkout operators' mid-line. After scanning and registering the products in the optical scanner, products were positioned immediately after the presence sensor in such a way that they slide towards the packing area (Figure 2).

All products handled had the same shape (0.15 x 0.10 x 0.07 m) and weighed 1.0 kg and were positioned lengthwise to match the direction of the conveyor belt displacement. Loads heavier or lighter than 1.0 kg are lifted in real working conditions, but they were not considered in the present study. Participants were allowed to perform the task during three minutes before data collection began and were requested to execute the task as naturally as possible. A pilot study showed little variation between trials, with a mean of 1.3º for all variables between each trial. Therefore, the mean of three trials was considered adequate to analyze the kinematics of the spine in each experimental condition.

The procedures used for the kinematic analysis were identical to those described by Rodacki et al[6]. Two calibrated and synchronized cameras sampling at 50 Hz were placed approximately 5 meters behind the workstation and allowed a 3D reconstruction of the trunk movements during the task in each experimental condition (standard and modified models). Six markers were positioned over the skin on the back of the participants: two over the spinous processes of C7 and S2; two positioned 4 cm laterally on either side of the midpoint line between L4 and S2; and two over the tip of each acromion. Images were stored in a tape and digitized at 30Hz using the SIMI software (Simi Motion®). The participants wore clothing that allowed the markers to be placed directly over the skin. The coordinates were filtered using a recursive Butterworth filter (4^{th} order) set at 7 Hz[17] and were used to reconstruct the movement in three planes.

A number of rigid segments were determined between spinal markers and used to analyze trunk segments in the frontal, sagittal and transversal planes. Lateral bending of the trunk in the frontal plane was calculated using the angle between S2 and C7 in relation to a horizontal line. Counter-clockwise changes in the frontal spinal profiles, as viewed from the rear (bending to the left side of the body), were considered as positive. Anterior-posterior bending of the trunk in the sagittal plane was calculated using the angle between S2 and C7 in relation to the horizontal line. Clockwise movements (flexion) were considered as positive, while counter-clockwise movements (extension) as negative. The degree of spinal rotation in the transversal plane was determined as the difference in rotation angles between the hips (defined by a straight line between the markers placed on L4 and S2) and shoulders (defined by a straight line between the acromion markers). Rotation to the right side was considered as positive and rotation to the left side as negative. Figure 3 provides a schematic representation of these angles.

The movement cycle was defined as the instant in which the first detectable movement of the trunk occurred from the erect posture to reach the object to the instant the hand lost contact with the object in the packing area. The combined average of three trials for each variable was used to represent each experimental condition. Before grouping the trials, a normalization procedure was applied. This procedure was performed by a computer routine using spline functions and its effect was deemed minimal because only temporal aspects were manipulated. Therefore, movement was expressed as a set of 101 data points,



The upper panel shows a schematic representation of the location of the points used to determine the kinematics of the trunk segment. The upper left figure shows the frontal plane (posterior view) and the C7 and S2 markers, while the upper right figure shows the sagittal plane. The bottom panel shows the schematic representation of the shoulders (acromion) and hip (iliac crest) from an overhead view. Note: the rotation angle was calculated using the relationship between shoulder and hip displacement.

Figure 3. Schematic representation of the biomechanical model (Adapted from Rodacki et al.[6]).

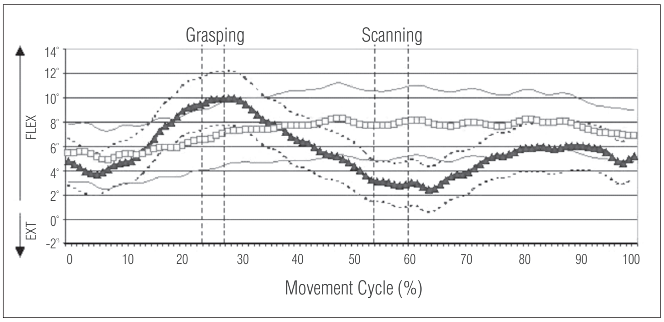


Figure 4. Trunk movement profiles in the sagittal plane while handling products in a standard checkout workstation (closed marks) and a modified checkout workstation (open marks). Thin lines represent one standard deviation. The approximate instants of grasping and scanning are identified by vertical lines.

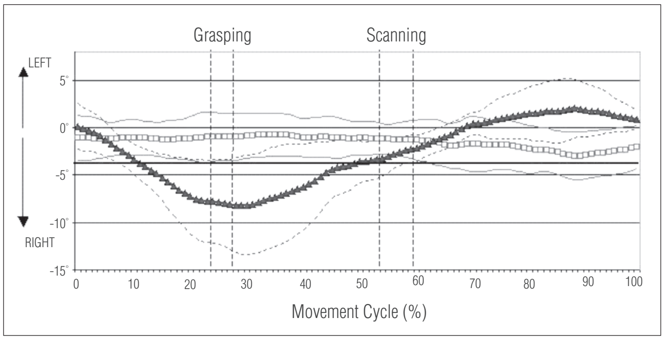


Figure 5. Trunk movement profiles in the frontal plane (posterior view) while handling products in a standard checkout workstation (closed marks) and a modified checkout workstation (open marks). Thin lines represent one standard deviation. The approximate instants of grasping and scanning are identified by vertical lines.

in which movement initiation and termination corresponded to 0% and 100%, respectively. To analyze the effect of each experimental condition, movements were compared with respect to the instants of product grasping, scanning and depositing.

The consistent pattern between radiographic and video analysis in the sagittal and frontal planes[18] encouraged the authors to discuss the findings of the present study assuming a close relationship between the kinematics of the trunk and the vertebral column. The spinal model and similar experimental approach is also similar to that reported by other studies (e.g. carrying a mailbag[19]) and was considered as adequate to the purposes of the present study.

To compare the variables across experimental conditions (standard and modified checkout workstations) the Student "t" test for dependent samples was applied. A Kolgomorov-Smirnov test was applied and confirmed data normality. The Bonferroni approach was applied to correct the significance level which was set at $p<0.05$. Descriptive statistical analyses (mean and SD) were employed to describe the characteristics of each variable. All statistical analyses were performed in the Statistica® package software, version 5.5 A (Stat Soft Inc.®, USA). Due to the small number of participants and the large variability of the kinematics, data must be considered with caution.

Results

The movements of the trunk in the sagittal plane were similar in both checkout workstations and significant differences were not detected during grasping ($p>0.05$). However, significant differences ($p<0.05$) were observed during scanning which showed greater anterior flexion of the trunk in the modified checkout workstation in comparison with the standard model. Figure 4 shows the spinal displacements in the sagittal plane, while Figure 5 shows spinal displacements in the frontal plane.

Lateral bending of the trunk during grasping products was significantly greater in the standard checkout workstation in comparison to the modified model ($p<0.05$). In contrast, no significant differences were detected during scanning ($p>0.05$).

Note that most actions performed using the modified checkout workstation produced minimal deviations from neutral (erect) posture, while the mean lateral bending range was much greater using the standard checkout workstation. The lateral bending to the left in the standard model was approximately three times greater than that observed in the modified checkout workstation.

The results did not show a significant effect (p>0.05) of the workstation design on trunk rotation in any of the selected instants. The mean rotation to the right side (product depositing) in the modified and standard checkout workstations was 3.7º±3.5º and 0.1º±2.9º, respectively. The mean rotation to the left side (product grasping) was 15.0º±7.7º and 15.8º±4.5º in the modified and standard checkout workstations, respectively. The largest rotation movements of the trunk (up to four times greater) were performed while grasping products, irrespective of the checkout workstation.

Discussion

Although numerous studies have proposed workstation modifications to reduce the risk of cumulative trauma disorders in supermarket checkout operators[6,20,21], no experimental studies have analyzed these propositions. Rodacki et al.[6] proposed a modified checkout workstation with a continuous conveyor belt that would position products near the checkout operator's mid-line to attenuate/reduce the postural demand of the task. The present study tested whether this particular modification was successful in minimizing postural demands and the risk of injury among supermarket checkout operators.

The comparison between the standard and the modified checkout workstations showed that the greatest postural changes occurred in the frontal plane. There was less lateral bending of the trunk to grasp products when participants performed the task using the modified checkout workstation, which can be considered beneficial in terms of postural strain. The maintenance of a neutral posture while using the modified checkout workstation can be considered an advantage in terms of reducing the postural demand and the risk of injury of the task. In general, asymmetric movements (i.e., lateral bending) combined with movements in other planes are intimately related with a number of low back disorders[22-24]. Lateral bending of the trunk can cause localized overload in the posterolateral inner annular region of the intervertebral discs of the lumbar area and predisposes to posterolateral prolapse of the nucleus pulposus[25,26]. This may also produce some loosening of the spinal ligaments leading to disc protrusion and degeneration. In addition, lateral bending overloads the apophyseal joints and predisposes participants to other critical conditions of the spine that may lead to discomfort and pain. The mechanical loading of the low back during handling of materials has been identified as a significant factor associated with the occurrence of low back pain.

Neumann et al.[27] used categorical scales to determine postural demands during the shift and reported that low-back pain is related to maximum flexion angle, peak spinal loads, average spinal loading and percent of time with loads in the hand. Although the flexion angles of the trunk observed in the present study remained unaltered in the sagittal plane, it is logical to assume that the reduced lateral bending angles in other planes (i.e., frontal plane) may also minimize the risk of injury in the modified checkout workstation. The modified checkout workstation allowed participants to handle products with the load close to their centre of mass and preventing the trunk to assume deviated postures. Deviated postures are well-known risk factors because the horizontal distance of the load to be lifted increases the muscle exertion to compensate for the differences in the flexor moment generated on the spine due to the substantial moment arm of the load.

Trunk rotation

Trunk rotation movements were analyzed considering the displacement of the shoulders with respect to the displacement of the hips. The modified checkout workstation failed to reduce the rotational movements of the trunk during the checkout operator's task. It was expected that positioning the load closer to the checkout operator's mid-line would allow smaller rotational movements. This can be explained in part by the movements of the upper limbs, which were able to reach products with relatively small movements of the trunk. In fact, the high incidence of musculoskeletal problems in the upper limbs – hands, wrists, elbows, shoulders and neck[21] – highlights the necessity for further studies. Rodacki et al.[6] showed that reaching and grasping light products are mostly performed by the upper segments and that more pronounced movements of the trunk occur when the weight of the load is increased. As the weight of most products handled by supermarket checkout operators fall bellow the weight used in the present study and the angular motion in relation to the full range of motion of the trunk is relatively small (similar to the erect posture), one repetition of the task should not be a concern. However, supermarket checkout operators perform a large amount of repetitive manual handling (1442 articles/hour[28]), and the cumulative effects of fatigue can become an important factor for low back and musculoskeletal disorders. Prolonged load carriage may produce adaptive responses of the musculoskeletal components and predispose to postural problems[29] and pain, leading to disability[30]. It would be interesting for future studies to investigate whether there is a cumulative effect of repeated loading that may lead to chronic postural adaptation. A plausible solution would be alternating the rotation side.

The results of the present study must be considered with caution as products (weight and shape) are not the same as those manipulated in real working conditions, which may be a limiting factor. In contrast, manipulating products with a wide variety of shapes and weights may introduce individual strategies and increase movement variability. Although all care was taken to reproduce the working condition as close as possible, other factors present in the checkout operator's routine (time demand, customer presence, charging customers and other perceived stress sources) may influence their actions.

Conclusions

Awkward, constrained, asymmetrical, repeated, and prolonged postures sustained by supermarket checkout operators have been reported[6] and possible solutions to reduce the inherent demand of the standard checkout workstation are required. The present study showed that a modified checkout workstation operating with a continuous conveyor belt is a possible solution to reduce the range of motion for trunk movements, particularly regarding lateral bending of the trunk. Therefore, it is suggested that this effect may contribute to reduce the incidence of back and postural problems among supermarket checkout operators. The use of a continuous conveyor belt allowed checkout operators to reach for products with minor postural deviations. The modified checkout workstation was considered as a workstation that may provide a reduced risk of injury in comparison to the usual checkout workstations because large range of motion and postural problems are closely related. These findings are relevant to reducing/minimizing the risk of injury, however other strategies (e.g. muscle strengthening, physical activity) must not be neglected as a preventive means for musculoskeletal problems. It is also necessary to emphasize that workstation changes are mandatory in those cases where the benefits derived from preventive or rehabilitative actions (e.g., strengthening, stretching physical therapy, etc.) cannot reduce or overcome the demand of the tasks involved in work. Other studies are required to determine whether the benefits suggested in the present study are also present over course of the work day, when fatigue may have pronounced effects. Epidemiological studies analyzing postural changes in relation to the number of years working as a supermarket checkout operator are required to confirm these speculations.

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