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An imperceptible barcode can reduce the muscle activity required to scan common consumer packaged goods

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ABSTRACT

While the Universal Product Code (UPC) has remained unchanged since its implementation in the 1970s, new technology and consumer package good layouts have started to change the UPC layout. The purpose of this study was to compare how upper extremity muscle activity was altered when scanning consumer packaged goods enhanced with an imperceptible barcode or a multi-sided UPC layout. Seventeen experienced cashiers participated in this study. Electromyography of four bilateral upper extremity muscles was recorded when scanning individual consumer packaged goods and a mock grocery cart. Scanning time and integrated electromyography were compared between the packages enhanced with an imperceptible barcode or the multi-sided barcodes versus the traditional barcodes. Participants were more efficient when scanning packages with the altered barcodes compared to the traditional barcode. Scanning the individual consumer packaged goods resulted in lower peak muscle activity for the shoulder muscles and elbow flexors when using packages enhanced with the imperceptible barcode. When extrapolated over a 4-h shift, the packages enhanced with the imperceptible barcode lowered upper extremity cumulative muscle activity measured muscles; however, the multi-sided layout only demonstrated a reduced muscular activity for the trapezius and left forearm. Future work must continue to assess grocery scanning practices, training, and other alternative scanning practices, such as hand scanners and self-checkout stands.

1. Introduction

The work environment of the supermarket cashier has long been a focus of ergonomic interventions related to the scanning and bagging of groceries. In 2017, the incidence rate of nonfatal occupational injuries and illnesses for supermarket employees in the United States was 157.2 cases/10,000 full-time workers, and 21.3 cases/10,000 full-time workers required at least one day away from work (Bureau of Labor Statistics U.S, 2019). The incidence rate of musculoskeletal injuries for cashiers (2018 Standard Occupation Classification 41-2011) was 13.7 cases/10,000 full-time workers (Bureau of Labor Statistics, 2019). The upper extremity was the most affected body part, and overexertion was the most commonly reported event at the time of injury (Bureau of Labor Statistics, 2019). Previous research has assessed checkout counter redesign (Draicchio et al., 2012), sitting versus standing check stands (Lehman et al., 2001), and enviro-packaging (Maciukiewicz et al., 2017). An advancement that has yet to be tested is how changes to the traditional Universal Product Code influence upper extremity muscle activity when scanning common consumer packaged goods.

In 1974, the Universal Product Code (UPC), first appeared on retail store consumer packaged goods (known as “packages” going forward). This barcode could be scanned by the retail cashier at the point of sale to efficiently price and register inventory (Basker, 2012; Rodriguez et al., 2015). The robust Universal Product Code of 1974 has stood substantially unchanged, and it is estimated to be scanned over 5 billion times per day (Rodriguez et al., 2015).

With advances in technology, companies have begun to expand their placement and printing of the UPC on packages. One such technological change is the enhancement of packages with a technology that is imperceptible to the human eye (Fig. 1). This means that the same data in a UPC barcode can now imperceptibly permeate the entire surface of a package. Another change implemented by some grocery

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Abbreviations

IB	Imperceptible Barcode
MB	Multi-sided barcode
tUPC	Traditional Universal Product Code
UPC	Universal Product Code

chains is to adopt “multi-sided” UPC placement, where the number, size, and shape of the UPC are altered compared to the traditional size and placement of the UPC (Fig. 2). Both of these designs may be beneficial to cashiers because they do not need to find one or two barcodes on each product. Instead, they can slide the item in any orientation over the scanner for identification. This may have benefits on cashier efficiency, but it may also reduce the required muscle activity because the cashier does not have to lift the product from the conveyer belt in order to scan the packages.

The purpose of this experimental study was to determine to what extent packaging enhanced with an *imperceptible barcode* (IB) or a *multi-sided barcode* (MB) design changes upper extremity muscle activity required to scan packages compared to the traditional UPC (tUPC). A secondary purpose was to determine if barcode type influences scanning time. We hypothesized that (1) participants would scan the alternate UPC designs faster than the tUPC packages, (2) scanning of heavier packages enhanced with an IB would require less muscle activity compared to the tUPC, (3) scanning a small grocery cart of packages with the alternate barcode designs would result in less muscle activity compared to the tUPC.

2. Methods

2.1. Participants

Seventeen female volunteers between the ages of 18–65 (age = 30 ± 12.8 years, height = 1.6 m ± 6.1 m, mass = 71.1 kg ± 18.3 kg) were recruited from grocery stores in the Northwest Arkansas area between the dates of July 20th to August 16th, 2017. Participants were currently employed as cashiers (average experience: 5.3 years ± 5.8 years) and had worked at least 1000 h in each of the past two years. Exclusion criteria for the study included previous shoulder, elbow, wrist, hand, or back injury. The study protocol received approval from the University of Arkansas Institutional Review Board and participants provided written informed consent before testing began.

2.2. Workstation

A checkstand was constructed to represent a typical cashier checkstand (Fig. 3). The height was set at 85 cm (33.5 inches). It consisted of an area representing the conveyer belt location, a mirrored scanner placed in the middle, and an area to receive the product after scanning.

Fig. 1. Example of the imperceptible barcode. Used with permission from Digimarc Corporation (Beaverton, Oregon, United States).

Participants were instructed to scan the items as if they had a bagger. The scanner contained software that recognized the imperceptible barcode; it could be toggled back and forth to recognize a traditional barcode only, or both the IB and the typical barcode. Scanning of the items went from right to left for all participants.

2.3. Consumer packaged goods

Consumer packaged goods with three types of barcodes were assessed in the study (Supplementary Material) – the imperceptible UPC (IB), traditional UPC (tUPC), and multi-sided UPC (MB). IB and tUPC were compared using the same packages that were recognized differently depending on how the scanner was toggled. The MB packages contained UPCs of a variety of sizes and numbers. For example, boxes usually had UPCs on four or five sides (there was never a barcode on the product face), or multiple and long UPCs that wrapped around jars or larger bagged items. The scanning of packages was evaluated in two different ways – by scanning individual products and by scanning a typical small grocery cart.

Six products were selected to be individually scanned – a box of moist towelettes, a box of crackers, a large can of pie filling, a bottle of sauce, a bottle of oil, and a bottle of juice. These products represented a range of sizes, masses, and shapes. The individual product comparisons were only made between IB and tUPC.

To emulate typical scanning in the workplace, the participant also scanned multiple items in a row. Four “grocery carts” containing 18 items were scanned to compare the IB and tUPC packages and the MB and tUPCs packages. IB and tUPC carts used the same packaging since the package enhanced with IB also contained a traditional UPC. For comparison with the MB, extra UPCs were blacked out using tape so that it resembled a traditional UPC package; therefore, there were two sets of the same product were compared.

2.4. Protocol

After informed consent was obtained, participants were shown an image of packaging enhanced with IB and were familiarized with a variety of packaging. Each person was allowed to practice scanning these items until comfortable. The same was done with the multi-sided products. Each person took about 5 min for this initial scanning.

Muscle activation of the right and left arm was monitored for each participant. Eight pairs of electromyography (EMG) bar electrodes (Trigno, Delsys Inc., Boston, Massachusetts) were affixed to the skin using double-sided tape over the following bilateral muscle groups – Upper Trapezius, Middle Deltoid, Biceps Brachii, and Flexor Digitorum Superficialis. Locations were defined according to standard protocols (Cram, 2011), and confirmed through palpation and manual resistance. Raw EMG was collected at a sampling frequency of 2000 Hz. Reference contractions were collected for EMG normalization so that all data

Fig. 2. Example of the multi-sided barcodes on a variety of different packages.

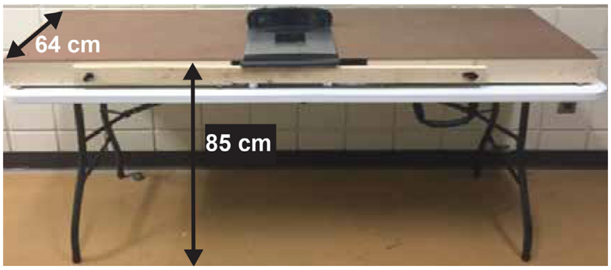

Fig. 3. Checkstand used in the study. Participants scanned from right to left.

could be expressed relative to the same exertion level. Reference contractions were used instead of maximum voluntary contractions to account for the broad age range of our study volunteers. This protocol is similar to what has previously been used for study participants with injuries (Ikeda and McGill, 2012). Since we were unsure of the capacity of our participants, this normalization protocol was chosen to account for a range of physical capacities across age groups. All reference contractions were performed bilaterally with the participant seated and held for 5 s. For the middle deltoid and upper trapezius, the participant held their arm at 90 degrees of abduction with a 1 kg weight on their wrist and thumb pointing forward. For the biceps brachii, the participant sat with their elbow bent at 90° with the palm facing up and 1 kg weight placed in their hand. For the flexor digitorum superficialis, the participant gripped a hand dynamometer with their thumb facing up and elbow at 90° and was instructed to grip as hard as they could. The dynamometer bar was aligned with the participant's second knuckle. Two trials were taken for each muscle, and the maximum value was used to normalize all subsequent trials.

This experimental protocol contained two stages – scanning of individual items and scanning of an entire grocery cart. Participants were instructed to start and finish with both hands on the checkstand:

- *Scanning of six individual items:* The scanner was set to identify either the IB or tUPC. The order that the participants scanned the items was randomized between the two barcodes. The participant received two practices for each item, and then two scans were recorded.
- *Scanning of four grocery carts:* Participants received one practice trial for each cart, and then two trials were recorded. The order that the participant scanned the carts was randomized.

2.5. Data analysis

All biomechanical data was analyzed in Visual3D (C-motion, Germantown, Maryland). The total trial length was estimated as the initial movement of the right hand until the left hand was placed back on the checkstand. To analyze the right and left arm separately EMG were terminated when the right and left hand was placed on the checkstand, respectively.

Electromyography data were bandpass filtered from 30 to 500 Hz, full wave rectified, and then low pass filtered at 4 Hz. EMG signals were then normalized to the peak activation from the reference contraction (RC) for each muscle. For the individual items, the peak muscle activity was extracted from each trial and expressed in units of %RC. For the grocery cart trials, integrated EMG was calculated by taking the area under the EMG time curve and expressed in units of percent reference contraction*seconds (%RC*s).

Since we hypothesized that scanning time would be affected by UPC type, we normalized the grocery cart trials to a 4-h block. A scanning practice can be more efficient and potentially result in lower cumulative muscle activity; however, when extrapolated over an entire shift this may mean that the cashier is seeing more customers. As a result, they may have an equivalent cumulative muscle activity over the same amount of time. The length of a sale was estimated to be the scanning time plus 30 s for the time between scanning the final product and the customer leaving the checkstand. This transaction processing time can fluctuate based on the payment type and advances in technology. Currently, a credit card or debit transaction that uses a chip takes 7–10 s (CNN, 2016). Factoring in the time it takes for the customer to insert their payment and to get a receipt, our pilot data found that this could take around 30 s per customer. The number of customers who could be served in 4 h was determined by dividing 4 h by the length of the sale. Cumulative integrated EMG over a 4-h shift was calculated by multiplying the number of customers scanned by the integrated EMG for the scanned grocery cart. As a note, we also ran our results with the transaction time being 15 s and there were no changes to the statistical results (results not shown).

2.6. Statistical analyses

All statistics were run in JMP Pro 13.0 (SAS Institute Inc., Cary, NC). The data for the scanning times did not follow a normal distribution, so Wilcoxon Signed Rank tests were run to compare the scanning times between IB and tUPC, and the MB and tUPC. Due to multiple comparisons, the *p*-value for significance was corrected to $p < 0.025$ (0.05/2 comparisons).

For the individual items, repeated measures analyses of variances were run on the peak EMG values for the flexor digitorum superficialis, biceps brachii, middle deltoid, and upper trapezius muscle activity with the factors of UPC (IB/tUPC), Package (6 packages) and Side (right arm or left arm). For the grocery cart items, repeated measures analysis of variances were run on the 4-h cumulative integrated EMG for the flexor digitorum superficialis, biceps brachii, middle deltoid, and upper trapezius muscle activity with the factors of UPC (IB/tUPC OR MB/tUPC) and side (right or left). All main effects were analyzed using Tukey post-hoc tests. The interactions were examined using simple effects. The significance level was set at $p < 0.05$ for all muscle activity outcome measures.

3. Results

3.1. Scanning time

There was a significant difference between the time required to scan packages with IB and MB packages in comparison to tUPC (Table 1). The IB and MB carts were scanned 6.6 s and 4.2 s faster than their tUPC counterparts, respectively.

3.2. Individual package scanning

For peak muscle activation, there were significant main effects of UPC for the Upper Trapezius ($p = 0.016$), Middle Deltoid ($p = 0.0167$), and Biceps Brachii ($p = 0.0074$). Peak muscle activation was highest for all muscles when scanning the tUPC packages.

A significant interaction of UPC*PACKAGE was found for the flexor digitorum superficialis muscle ($p = 0.0478$). For both the crackers and the wipes, the muscle activity was higher when scanning the products

Table 1
Comparison of scanning time (seconds) and products scanned per minute between the imperceptible (IB) and multi-sided (MB) barcode packages and traditional Universal Product Code packages (tUPC).

	Mean	Standard Deviation	95% CI	*p*-value
Time (seconds)				
IB	21.1	3.5	19.3–22.9	< .0001
tUPC	27.7	5.9	24.6–30.7	
MB	20.3	4.7	17.8–22.7	.0017
tUPC	24.5	5.9	21.8–27.8	

with the tUPC packages (Crackers: 26.4%RC, SD = 23.9%RC; Wipes: 25.9%RC, SD = 18.4%RC) compared to the IB (Crackers: 18.0%RC, SD = 16.7%RC; Wipes: 16.8%RC, SD = 11.5%RC).

A main effect of PACKAGE was found for the Biceps Brachii ($p < 0.0001$) and Upper Trapezius muscles ($p = 0.0369$). For the Biceps Brachii, the oil and juice products elicited a higher peak muscle activity compared to the other products. For the Upper Trapezius, peak muscle activity was higher when scanning the juice versus the wipes ($p = 0.0195$). Lastly, there was a significant main effect of SIDE for the Biceps Brachii ($p = 0.006$). The right arm had a higher peak muscle activity (117.9%RC; SD = 94.2%RC) compared to the left arm (52.5% RC; SD = 62.2%RC).

3.3. Grocery cart scanning

Cumulative integrated EMG over a modelled 4-h shift – IB vs. tUPC: There was a significant main effect of UPC type for each muscle (Fig. 4). For all muscles, the cumulative integrated EMG was higher when scanning the tUPC grocery cart. There was no difference between the right and left sides.

Cumulative integrated EMG over a modelled 4-h shift – MB vs. tUPCs: The only main effect of UPC type was found for the upper trapezius ($p = 0.0027$). Cumulative integrated EMG was higher when scanning the tUPC grocery cart (Fig. 5). There was also a significant SIDE*UPC interaction for the flexor digitorum superficialis ($p = 0.0128$). UPC type influenced the left forearm ($p = 0.0032$), but not the right forearm ($p = 0.9530$). For the left side, cumulative integrated EMG was higher when scanning the tUPC grocery cart.

4. Discussion

The purpose of this experimental study was to determine to what extent packaging enhanced with an imperceptible barcode or a multi-sided design changes upper extremity muscle activity required to scan packages compared to the traditional barcode. Our participants were more efficient (hypothesis 1) when scanning with the imperceptible and multi-sided barcode packages compared to the traditional barcode packages. Scanning individual imperceptible barcode packages (hypothesis 2) resulted in lower peak muscle activity for the shoulder and elbow flexors; however, the forearm demonstrated a significant interaction with barcode type and package, with the boxed packages with an imperceptible barcode demonstrating lower peak muscle activity. When extrapolated over a 4-h shift, the using the imperceptible barcode resulted in lower cumulative integrated EMG for each collected muscle (hypothesis 3); however, the using the multi-sided barcode only reduced cumulative integrated EMG for the upper trapezius and the left flexor digitorum superficialis.

In general, implementing the imperceptible barcode reduced upper extremity muscle activity in the collected muscles. For the individual packages, this peak activation was decreased for the elbow and shoulder muscles, regardless of the package. The exception to this was the flexor digitorum superficialis, which only demonstrated decreased peak muscle activation when scanning the boxed packages (crackers and wipes). Scanning boxed packaging can be accomplished by sliding the product across the scanner rather than lifting it to scan; therefore, the finger flexors may not have been required to the same level to secure the packages. When scanning heavier items, barcode type did not influence peak muscle activation of the flexor digitroum superficialis. Heavier or breakable packages (i.e., a large bottle of oil or a glass bottle), still need to be safely secured in the hands; therefore, packaging

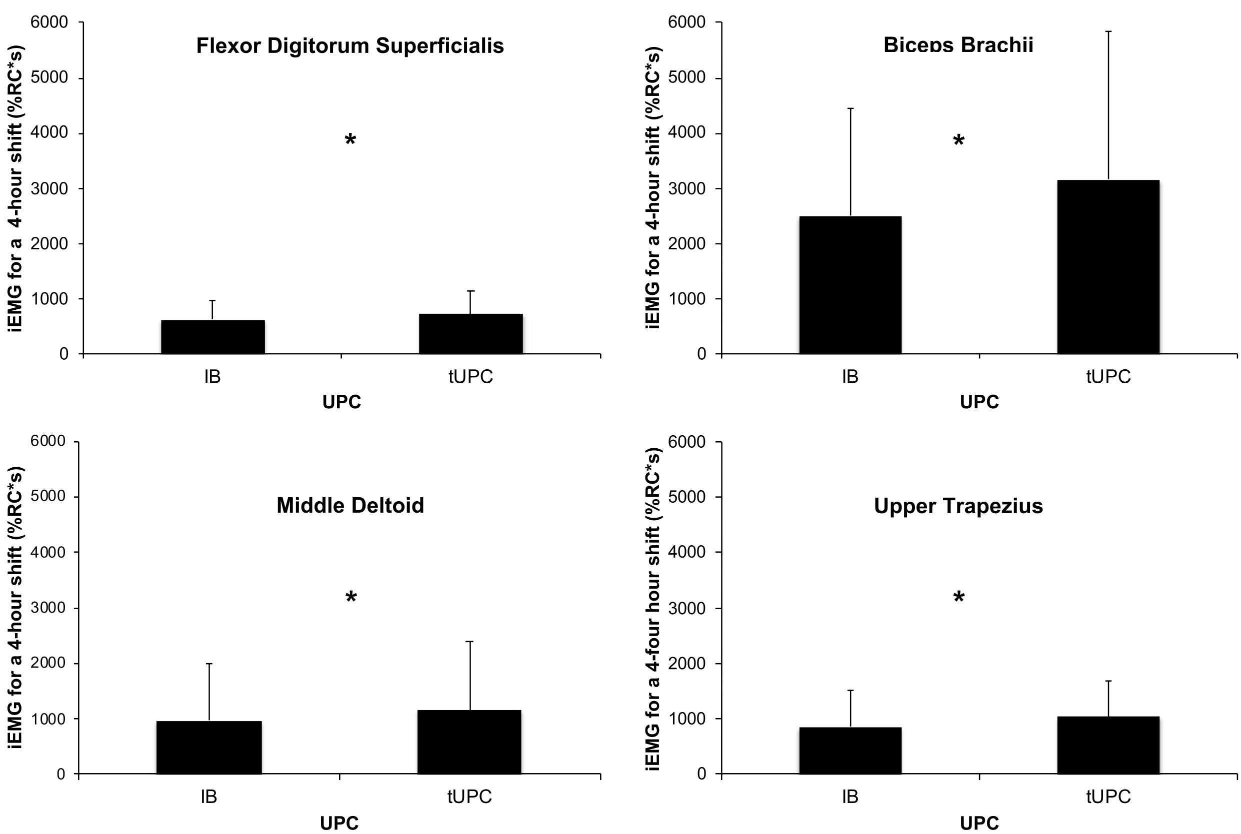

Fig. 4. Comparison of cumulative integrated EMG (mean and standard deviation) between the imperceptible barcode (IB) and traditional universal product code (tUPC) grocery carts for a modelled 4-h cashier shift. There was a significant difference (*) between the IB and tUPC for each muscle.

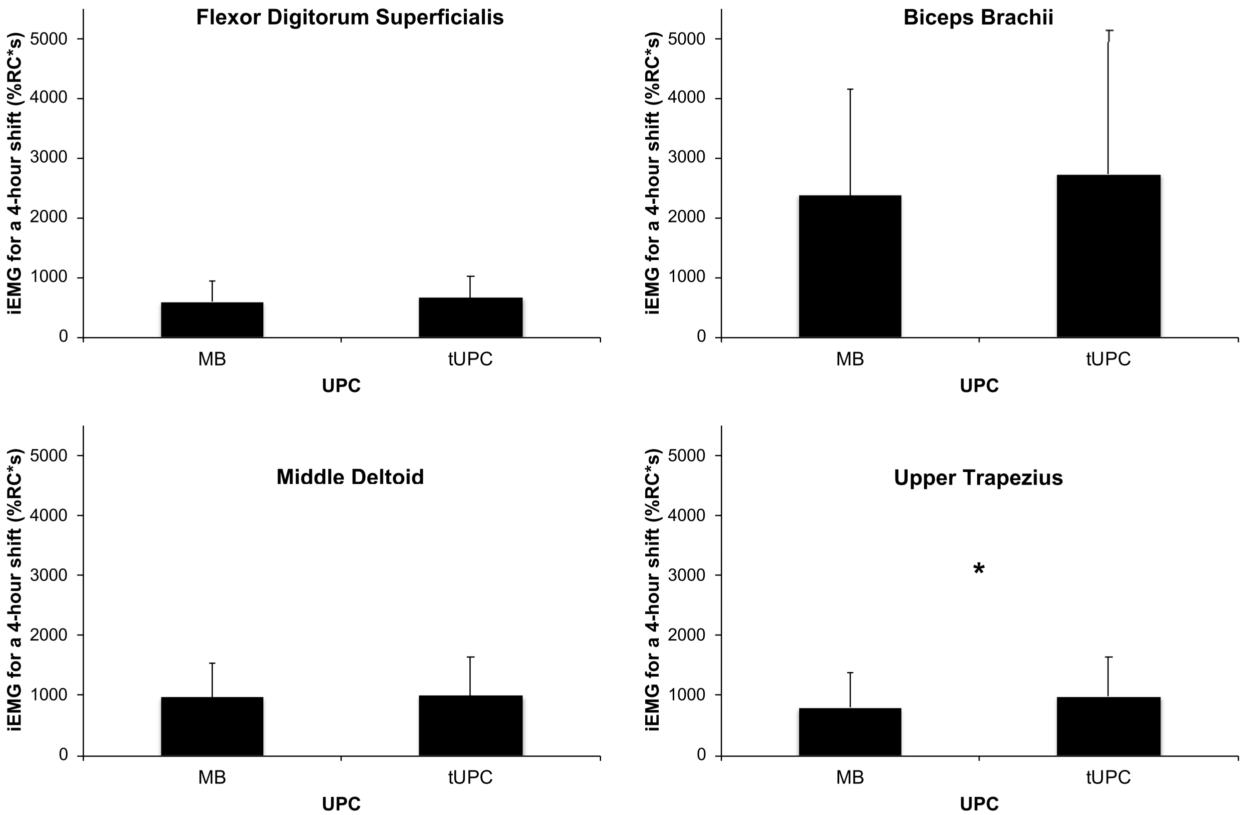

Fig. 5. Comparison of cumulative integrated EMG (mean and standard deviation) between the modified barcode (MB) and traditional universal product code (tUPC) grocery carts for a modelled 4-h cashier shift. The only significant difference (*) was for the upper trapezius muscle.

type, rather than the barcode type, may have a greater impact when scanning items that are heavy or easily damaged. Grasping heavy packages also increase trunk flexion and lateral bending (Rodacki et al., 2006). Left forearm and upper trapezius cumulative muscle activity were lower when scanning the multi-sided barcode packages compared to the traditional barcode packages. While the right hand was still picking up the packages to be scanned, the left hand may not interact with the packages to orient the barcode correctly as it would have with the traditional barcode packages.

Due to package availability, a limitation of our study was that the imperceptible and multi-sided barcode packages could not be compared directly. Second, since the participants' exposure to the multi-sided barcode varied, their previous experience could have influenced the results; however, the ability to adopt a quicker scanning time when using packaging enhanced with an imperceptible barcode was found even though it was their first exposure to scanning the packages. We also did not factor in the bagging process. Participants were instructed to scan as if they had a bagger, and an experimenter immediately removed items after scanning. Many participants who are also responsible for bagging the products said that it influences their scanning order. For example, some participants wanted to scan all cans first since they were the heaviest. Since the consumer does not always sort their items in this way, cashiers could be reaching over and around products to pick up particular items. These variations in scanning technique could influence scanning time and physiological variables. Lastly, we chose a fixed stand height to replicate most check stands in the field; however, participant height may have influenced scanning time and muscle activity. For example, shorter participants may display higher upper extremity muscle activity during scanning on a checkstand that is too high. It is possible that the imperceptible and multi-sided barcode could help shorter cashiers since they would not have to lift the packages as much. As a result, future work should look into the interaction of scanner height and barcode type.

While the imperceptible barcode demonstrates an increased efficiency and reduction in cumulative muscle activity, its success is dependent on the cashier's workflow practices and training protocols. In stores where the cashier is responsible for scanning and bagging items, some cashiers indicated that they would sort through the products on the belt rather than scan the products in order. As a result, cashiers pick up items by reaching over other products. This workflow could increase scanning time, shoulder and elbow muscle activity, and range of motion. As a result, the positive benefits gained by using the imperceptible barcode could be negated if the cashier still scans like this once this barcode is implemented.

The above is an example of how a workplace's philosophy and training practices influence workflow. When implementing this barcode strategy, it will be essential to know how a store trains their employees on using their checkstands and if they provide training of best practices for product scanning. It may be that cashiers only get trained on the system, but not on best practices. As a result, they will scan in ways that are best for their checkstand environment, rather than what is best for efficiency or preventing an injury. Other stores may train their employees on the system, how best to interact with the products, and discuss the benefits of working optimally. The awareness of these issues and recommendations on how an employee is trained to scan packages that are enhanced with an imperceptible barcode will be necessary for successful adoption. An example strategy would be to provide ergonomics training to cashiers in a similar way to what has been examined in office workplaces (Robertson et al., 2013). An extended training session could be used to review basic ergonomic principles (such as not reaching over items and avoiding awkward postures) and hands-on practice periods with the imperceptible barcode. The session would also go over the benefits of changing scanning practices, such as not reaching over items, one's health. Participants would then have an experiential practice period and receive reminders throughout their shift regarding scanning ergonomics principles.

Lastly, with many stores adopting self-checkouts, it will be important to communicate the implementation of the imperceptible barcode to consumers. The reason being, unlike a finite group of trainable employees, most consumers will enter the store unfamiliar with packaging or scanning practices. Since these barcodes are imperceptible, educating the customer will crucial for implementation and utilization. Consumers may still search for barcodes or extensively interact with products during the scanning process. Such interactions could then decrease their efficiency at the self-checkout stations or make the change useless if customers do not benefit from the system's full capabilities.

Decreased scanning time and reduced upper extremity muscle activity were found when scanning packages enhanced with the imperceptible barcode compared to packages with traditional barcodes. The effect was still evident after the muscular activity from the grocery cart that was modelled to represent a 4-h shift. While the MB packages also presented a decrease scanning time over one trial, the same differences were not evident when muscle activity was modelled over a 4-h shift. Future work must continue to research the implementation strategy of the IB and its use with alternative scanning practices, such as hand scanners and self-checkout stations.

Competing interest statement

No authors have competing interests to report. The work itself was funded as part of an industry grant from Digimarc Corporation. Researchers were independent of the funder in the study design methodology, data acquisition, data analysis, and interpretation. The imperceptible barcode was from Digimarc Corporation.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2019.04.009.

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