IISE Transactions on Occupational Ergonomics and Human Factors

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uehf21

# Field Observation of Hospital Food Service Workers and the Relationship between Customer Demand and Biomechanical Stress: A Case Study

Vernnaliz Carrasquillo, Thomas J. Armstrong & S. Jack Hu

**To cite this article:** Vernnaliz Carrasquillo, Thomas J. Armstrong & S. Jack Hu (2022) Field Observation of Hospital Food Service Workers and the Relationship between Customer Demand and Biomechanical Stress: A Case Study, IISE Transactions on Occupational Ergonomics and Human Factors, 10:1, 47-58, DOI: 10.1080/24725838.2021.2018372

**To link to this article:** https://doi.org/10.1080/24725838.2021.2018372

Published online: 24 Dec 2021.

IISE TRANSACTIONS ON OCCUPATIONAL ERGONOMICS AND HUMAN FACTORS
2022, VOL. 10, NO. 1, 47–58
https://doi.org/10.1080/24725838.2021.2018372



CASE REPORT

# Field Observation of Hospital Food Service Workers and the Relationship between Customer Demand and Biomechanical Stress: A Case Study

Vernnaliz Carrasquillo, Thomas J. Armstrong, and S. Jack Hu

Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI, USA

**OCCUPATIONAL APPLICATIONS**
Motion analysis of three workers at a large hospital kitchen was conducted using video recordings as part of this case study. Workers were observed during both a high-demand period and a low-demand period to evaluate their exposure to physical risk factors for work-related musculoskeletal disorders. On average, workers' reaching posture did not change significantly with customer demand. However, recovery time decreased by 18% and hand activity level (HAL) increased by 27% when customer demand increased. On an individual basis, the only worker whose work pace was constrained by processing (cooking) time and the availability of materials to complete the tasks had the most recovery time and did not show an increase in HAL even with an increase in demand. These results suggest the importance of designing tasks that are paced externally (e.g., cooking time) in a self-paced operation to limit the reduction in recovery time and increase in HAL as demand increases.

**ARTICLE HISTORY**
Received 27 January 2021
Accepted 10 December 2021

**KEYWORDS**
Hand activity level; recovery time; field observation; reaching posture; customer demand; work pace

## 1. Introduction

This case study investigated the relationship between customer demand and biomechanical stresses among commercial kitchen workers. It was expected that exposure to physical risk factors for work-related musculoskeletal disorders (WMSDs) would increase as customer demand increases. Specifically, reaching and repetitive exertions will increase while recovery time will decrease as customer demand increases.

Nearly 800,000 people in the United States work in commercial kitchens preparing food every year. Approximately 8% of these are employed by hospitals and social assistance centers to provide meals to patients and clients. WMSDs caused by repetitive motion and overexertion ranked as the greatest source of reported injuries among commercial kitchen workers, with an incidence rate of approximately 54 cases per 100,000 full-time workers (U.S. Bureau of Labor Statistics, 2019). Workers in commercial kitchens continually use their hands to reach food items, prepare food, move heavy containers, and move completed plates and trays. Variable customer demand leads to periods of time when the workers are continuously busy with little time available for recovery. These working conditions may contribute to overexertion and high repetition with insufficient recovery time, known physical risk factors for WMSDs (Bernard, 1997; Costa et al., 2010; National Academy Press, Washington, DC, 2001).

The prevalence of WMSDs among hospital kitchen workers due to overexertion and repetition in hospital kitchens has been reported by Alamgir et al. (2007). They surveyed hospitals in Canada and found an incidence rate of 18.3 injuries per 100 person-years. da Luz et al. (2013) reported that overexertion has also been associated with the development of circulatory disorders of the lower limbs among the kitchen staff in healthcare facilities. Because of the reports on these types of injuries, studies have investigated which specific aspects of the work contribute to the exposure to these physical risk factors. A study conducted in a hospital (Chim, 2006) identified the workstations that were more likely to increase worker exposures. Among the workers tasked exclusively with preparing trays, those workers placing the completed trays in the delivery carts were at higher risk than all the other tray assembly line workers. This elevated risk was due to frequent bending while holding a full tray. A study conducted in a similar hospital kitchen (Carrasquillo et al., 2011) found that as the variety of foods available for a worker to place on the tray increased, so

**CONTACT** Vernnaliz Carrasquillo vcarrasq@emich.edu Industrial and Operations Engineering, Eastern Michigan University, Ann Arbor, MI, USA.

did the frequency of reaching outside the reach envelope while the amount of time available for recovery decreased. Both of the latter studies were conducted in hospital kitchens where trays were placed on a moving conveyor. Workers had stations assigned without much space to move and without fluctuations in customer demand. A study conducted in a somewhat similar environment, a university cafeteria, investigated which tasks presented higher exposure to non-neutral postures and high repetition, among other physical risk factors based on the characteristics of the workstation layout (Kamat et al., 2017). The workers in the cooking and dishwashing areas were found to be at greater risk of overexertion due to poor workstation design than the workers in the drink and cash register areas. None of these studies, however, evaluated the effect of customer demand or frequency of exertion in the assessment.

Additional research concerned with the health of workers of commercial kitchens has focused on other physical risk factors for WMSDs. For example, Matsuzuki et al. (2013) investigated whether a new hospital kitchen layout had any effect on staff workload and job-related stresses. However, their study focused on measuring workload and stresses using fluid loss, heart rate, and metabolic equivalents of tasks, but did not compare posture and recovery time before and after the changes. Other studies have focused on additional physiological measures (Aminoff et al., 1999) or the effectiveness of reflection groups in the implementation of ergonomics recommendations within the hospital kitchen staff (Glina et al., 2011).

Work in hospital kitchens may be analogous to the work in a manufacturing plant, given the repetitive nature of many of the tasks conducted. These repetitive tasks include getting meal orders, setting up a tray, transporting a tray between stations via a conveyor, and removing the tray from the conveyor to place it on a cart. Utilizing concepts traditionally used for manufacturing plants, Moatari-Kazerouni et al. (2015a) developed a risk estimation method that they later used during the design of a new hospital kitchen (Moatari-Kazerouni et al., 2015b). While their study did not assess overexertion or repetition, using this method they were able to improve the working conditions by reducing noise and chemical exposure.

The similarity between commercial kitchen work and manufacturing allows for the use of assessment tools for exposure to physical risk factors for WMSDs. The "Hand Activity level" (HAL) scale (Latko et al., 1997, 1999) – which is used to evaluate the frequency of exertions and became the basis of the ACGIH TLV ® (ACGIH, 2019a) for preventing hand, wrist, and forearm WMSDs – is one of the tools that can be useful in assessing the demands of a kitchen environment on the workers. One way in which this environment differs is in the fluctuations in demand throughout the day. In the hospital kitchen environment, where output requirements change throughout the day, it is expected that the frequency of exertions will increase while the time available to recover will decrease with increasing customer demand. Additionally, workers may reach to get and place work objects, rather than take a step, to reduce energy expenditure.

In this case study, worker reaching posture (reach), HAL, and recovery time were evaluated in a hospital kitchen with a manual assembly line where mass customization of products (meals) are prepared on demand. In mass customization manufacturing, the aim is "to deliver products and services that best meet individual customer needs with near mass production efficiency" (Tseng & Hu, 2014, p. 836). Doing so, though, leads to greater work content and material variations throughout the day. While in a paced assembly line such variations may lead to increased reaching and reduced recovery time (Carrasquillo et al., 2011), the results from Carrasquillo et al. (2017) indicated that in a self-paced assembly line as studied here, both worker reaching and recovery time may be decreased.

In summary, commercial kitchen work involves intense use of the hands in a self-paced environment where customer demand may influence the frequency of exertions and available recovery time. WMSDs caused by repetitive motion and overexertion are the greatest source of injuries among these workers. Although others have evaluated some aspects of worker safety in commercial kitchens, the present study is the first to evaluate specifically how customer demand and work pace affect worker exposure to the physical risk factors that may contribute to these injuries in a kitchen environment.

## 2. Methods

A case is presented to explore the above concepts and provide a discussion of how the work demand affects recovery time, HAL, and reaching posture. Three hospital food service workers who prepared food on demand were observed. Video recordings were used to determine and compare the work steps or elements, recovery times, and reaching posture patterns.

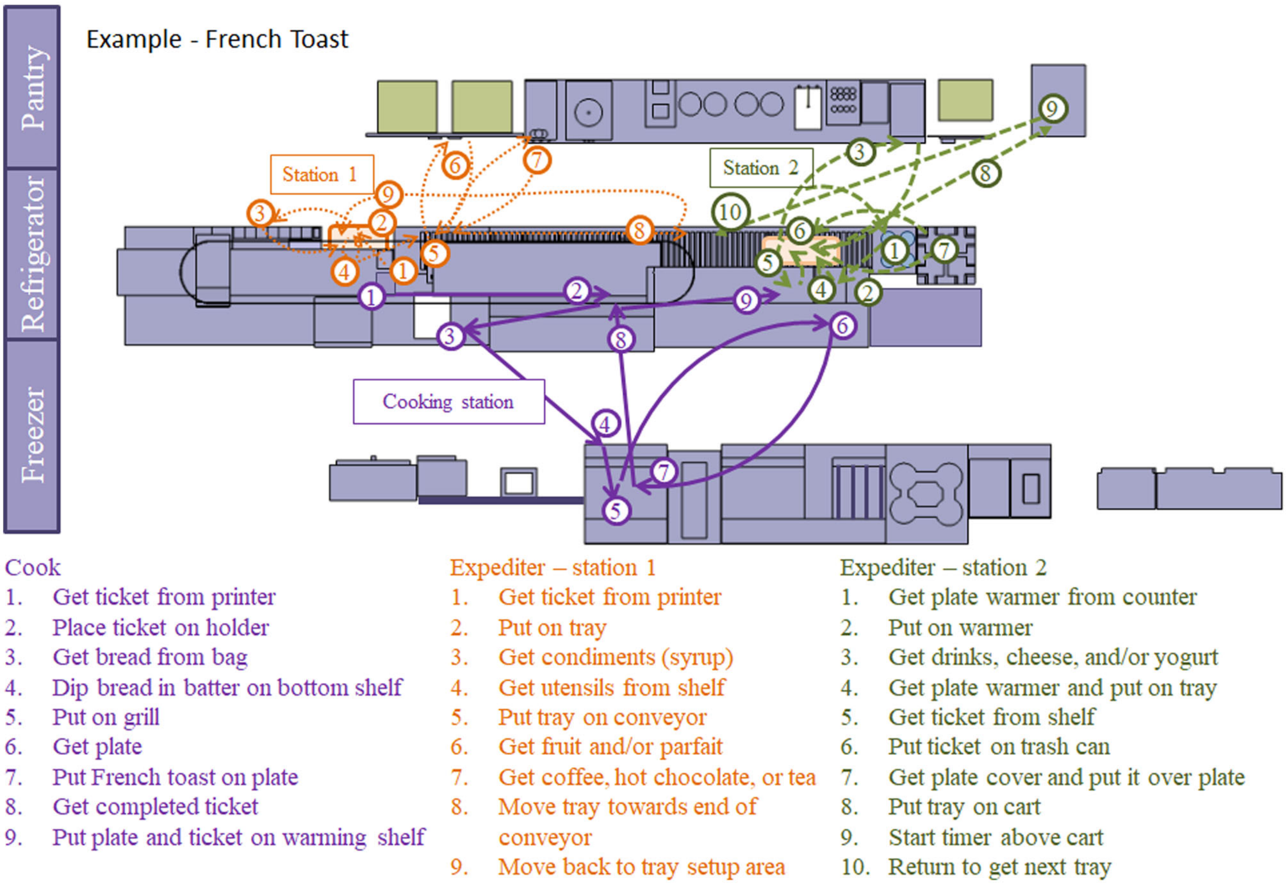


**Figure 1.** Plan view of the kitchen, showing the movement of workers. In this example, workers are preparing a tray with French toast, one of the most frequently ordered breakfast items from the menu. While the cook prepared French toast, the expediter positioned at Station 1 prepared the tray with utensils, drinks, and sides, and the expediter positioned on Station 2 gathered other sides, placed the cooked French toast on the tray, and placed the tray in the cart to be taken to the patient's room. The cook was the worker whose tasks varied the most depending on the order.

### 2.1. Study Site

This study was conducted in a large hospital kitchen divided into two main areas: (1) food preparation; and (2) tray assembly. The cooks prepared and served hot foods. Figure 1 shows the expediters in station 1 and station 2. They placed utensils, side dishes, and the meals prepared by the cooks on trays that moved along a manual conveyor. Patients could order meals at any time between 6:30 AM and 8:00 PM. The food delivery lead time target was set to 45 minutes. To achieve this target, the hospital kitchen staff strived to complete the trays within 30 minutes.

### 2.2. Participants

Informed consent was obtained from workers in the morning shift following a protocol approved by the Institutional Review Board at the University of Michigan. Data were collected between 6:30 AM and 1:00 PM. The hospital kitchen staff consisted of one cook (male, age 38, height 177 cm, mass 74 kg), and two expediters (both females, ages 21 and 26, heights 164 cm and 178 cm, and masses 56 kg and 65 kg).

### 2.3. Data Collection

Hospital order records were collected for three nonconsecutive days. These records were used to determine two, 30-minute order periods, one with high demand and another with low demand. Video cameras were used to record the workers during each of the two work periods for 25 – 35 minutes. Windows Movie Maker software was used to perform a frame-by-frame motion analysis study of the workers' dominant hand and to estimate the frequency and type of reaching, amount of recovery time, and the HAL (ACGIH TLVs and BEIs, 2016). Table 1 shows a sample of the data collection used for analysis.

### 2.4. Dependent Variables

#### Reaching Posture

Reaching posture was characterized using an adaptation of the Rapid Upper Limb Assessment (RULA;

**Table 1.** Sample of data collection summary.

| Start | Finish | Δt (s) | Motion | Item | Comment | Reach category | Motion constrained/unconstrained |
|---|---|---|---|---|---|---|---|
| 00:00.0 | 00:04.5 | 4.5 | Put | Sides | On plate | Upper arm | Constrained |
| 00:04.5 | 00:08.3 | 3.8 | Reach | Shelf | Put plate on shelf, get ticket and put with plate | Upper arm | Constrained |
| 00:08.3 | 00:11.2 | 2.9 | Reach | | Frying pan, and get a pancake | Upper arm | Unconstrained |
| 00:11.2 | 00:15.0 | 3.8 | Walk | | To sides bar | Recovery | |
| 00:15.0 | 00:17.3 | 2.3 | Put | Sides | On plate | Lower arm | |
| 00:17.3 | 00:20.1 | 2.8 | Reach | Shelf | Put plate on shelf, get ticket and put with plate | Upper arm | Constrained |
| 00:20.1 | 00:25.8 | 5.7 | Get | Pancakes | Walk to frying pan and put 2 pancakes on plate | Upper arm | Unconstrained |
| 00:25.8 | 00:28.1 | 2.3 | Walk | | To sides bar | Recovery | |
| 00:28.1 | 00:30.0 | 1.9 | Reach | Sides | Put sides on plate | Upper arm | Constrained |


**Figure 2.** Reach types: (a) lower arm reach, (b) upper arm reach, and (c) torso bent/twist.

McAtamney & Corlett, 1993). Posture was categorized as follows:

- Lower arm reach – lower arm flexed 60° - 100°, while the torso and upper arm were flexed or abducted/adducted less than 20° (Figure 2(a))
- Upper arm reach – upper arm flexed and/or abducted/adducted more than 20°, while the torso was bent less than 20° (Figure 2(b))
- Torso bent/twist – lower and upper arm flexed and/or abducted/adducted, torso flexed or twisted greater than 20° (Figure 2(c))

Workers reached outside their reach envelope (Figure 3) for various reasons. Because of this, the upper arm and the torso bent/twist reaches were further categorized into:

- Constrained (Figure 4(a)) – These reaches were dictated by the worksite layout. They occurred when the workers were getting/putting a food item from/on a location at a height or depth beyond their reach envelope (Figure 3). As a result, their reach type was constrained by the worksite layout.
- Unconstrained (Figure 4(b)) – These reaches occurred when workers used their upper arm and possibly their torso even though it was not required by the location of the work objects (Figure 3). For example, Figure 4(b) shows the expediter in Station 1 placing items on a tray. Had

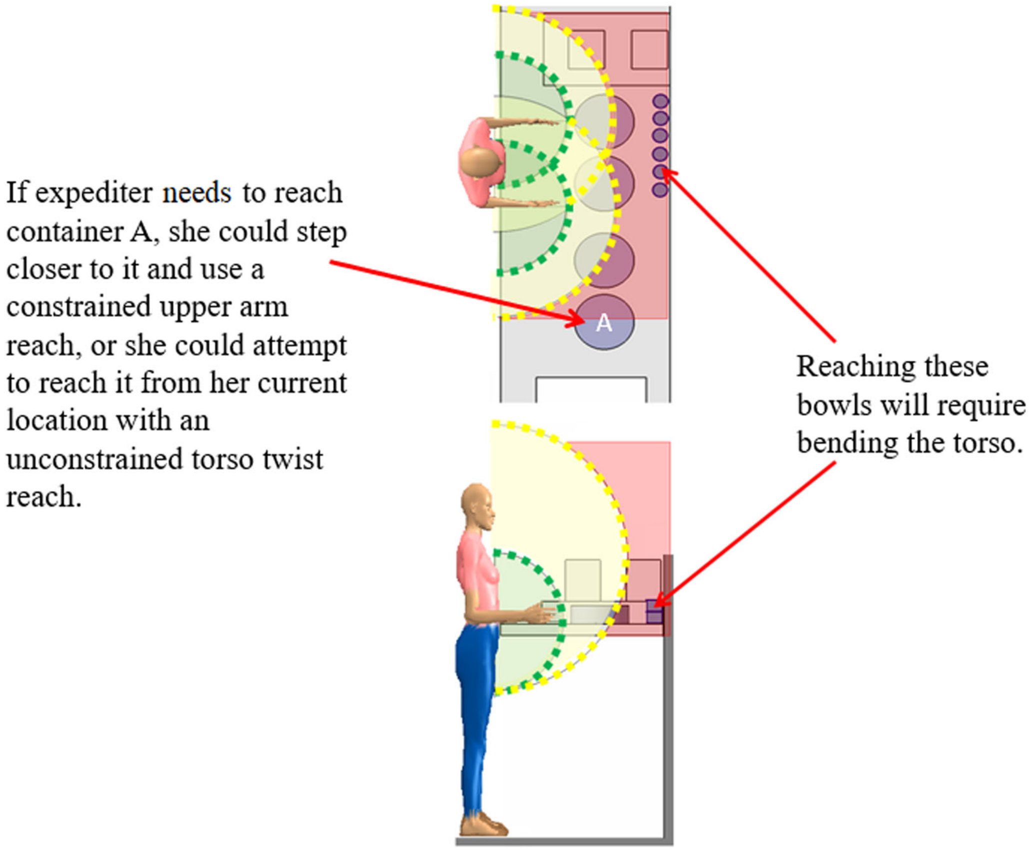


**Figure 3.** Side and top views of the manikin and reach envelope of expediter working in Station 1. The green zone may be reached with the lower arm, the yellow zone requires the use of the upper and lower arm. Reaching beyond these zones requires bending or twisting of the torso. This figure shows an example of objects that are outside the reach envelope and require the worker to assume a non-neutral reaching posture to complete the task.

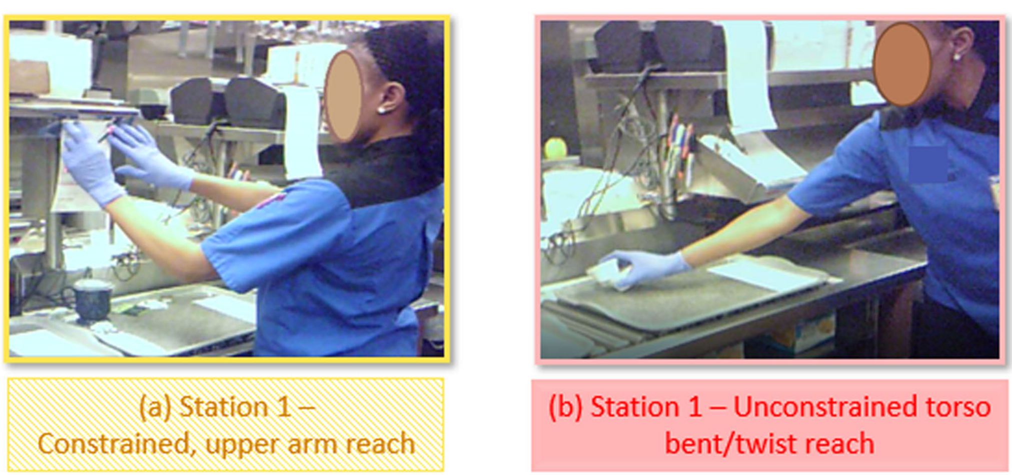


**Figure 4.** Examples of constrained and unconstrained reaches.

she taken 2 more steps, she could have reached the tray using her lower arm only.

The percentage of reaching in each category was calculated by counting the number of reaches in each category and dividing it by the total number of reaches. Equation (1) shows the formula used to calculate the percentage of reaching using the lower arm.

$$\%reaching_{lower\ arm} = \sum of\ lower\ arm\ reaches / \sum of\ all\ reaches * 100\% \quad (1)$$

For example, if using the data in Table 1, the % reaching with the lower arm during the observed 30 seconds would be calculated as % $\text{reaching}_{\text{lower arm}} = 1/7*100\% = 14.3\%$.

### *Recovery Time*

Recovery of the upper extremities was defined as resting time or times when the worker was not manipulating, holding, moving, or reaching for objects, or performing actions that did not require the use of the hands (e.g., read order ticket, walk with empty hands). Recovery time was calculated by adding all of the time the worker spent in recovery ($\Delta t_{recovery}$) and then dividing it by the total observed time ($\Delta t$):

$$\%recovery\ time = \sum \Delta t_{recovery} / \sum \Delta t * 100\% \qquad (2)$$

Using Table 1 as an example, the % recovery time during the observed 30 seconds would be calculated as % recovery time = $(3.8+2.3)/(4.5+3.8+2.9+3.8+2.3+2.8+5.7+2.3+1.9)*100\% = 20.3\%$. In this example, the time spent walking was the only work-related task classified as recovery time.

### *Hand Activity Level (HAL)*

HAL was scored using the scale developed by Latko et al. (1997). Because workers performed tasks to complete more than one meal order at a time, none of these measurements could be separated by individual working cycles. Additionally, work-rest cycles could be as short as 2.1 seconds or as long as 306 seconds, with duty cycles that varied from 13% to 99%. Instead of recording HAL for each work-rest cycle, it was recorded every 30 seconds using a visual analog scale (ACGIH, 2016; Latko et al., 1997).

### *2.5. Statistical Analysis*

The Marascuilo procedure (NIST/SEMATECH, 2013), which is used to simultaneously test the differences between multiple pairs of proportions, was used to compare the frequency of reaching and recovery times between the high-demand (breakfast) and low-demand (transition) periods. Significance was determined at $\alpha = 0.05$. For the HAL, 95% CI intervals for normal distributions were used to determine significant differences.

## 3. Results

### *3.1. Order Records Analysis*

Stored paper records of the orders were analyzed to find the high and low-demand periods (Figure 5). The high-demand period occurred during breakfast time (8:45 AM – 9:15 AM), when 121 orders were received. The low-demand period occurred during the mid-morning transition between breakfast and lunch times (11:15 AM – 11:45 AM), when 64 orders, approximately 50% of the orders during the high-demand period, were received.

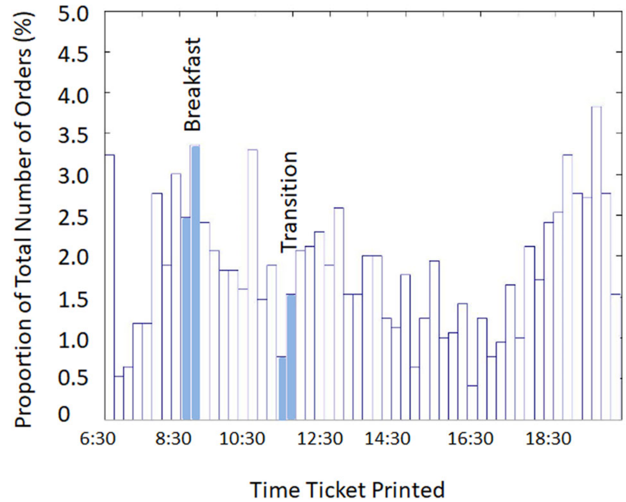


**Figure 5.** Meal order distribution throughout the day during three nonconsecutive days. The shaded bars represent the times selected as high demand (breakfast) and low demand (transition between breakfast and lunch).

### *3.2. Reaching Posture*

The overall proportion of reaches where the workers used only their lower arms was not significantly ($p > 0.05$) affected by demand; 37% (SD = 3%) at high demand and 33% (SD = 3%) at low demand (Figure 6). However, because fewer trays were prepared during the transition time, the total number of reaches decreased by 100 as demand decreased by approximately 50% (509 reaches observed during high-demand periods, 409 reaches observed during low-demand periods). Similar results were found for the proportion of unconstrained and constrained reaches utilizing the upper arm and the torso. These results show that regardless of the demand, workers overall used their upper arms and torso to reach objects (constrained and unconstrained) more than half of the time.

Each workstation was also analyzed independently (Figure 7). Expediters in stations 1 and 2 showed no significant ($p > 0.05$) differences in reaching between the different demand periods. However, the cook's unconstrained reaches using the torso increased by 8% as the demand decreased.

### *3.3. Recovery Time*

Overall, the recovery time was greatest during the low-demand involved work cleaning up and lunch setup. The recovery time significantly ($p < 0.05$)

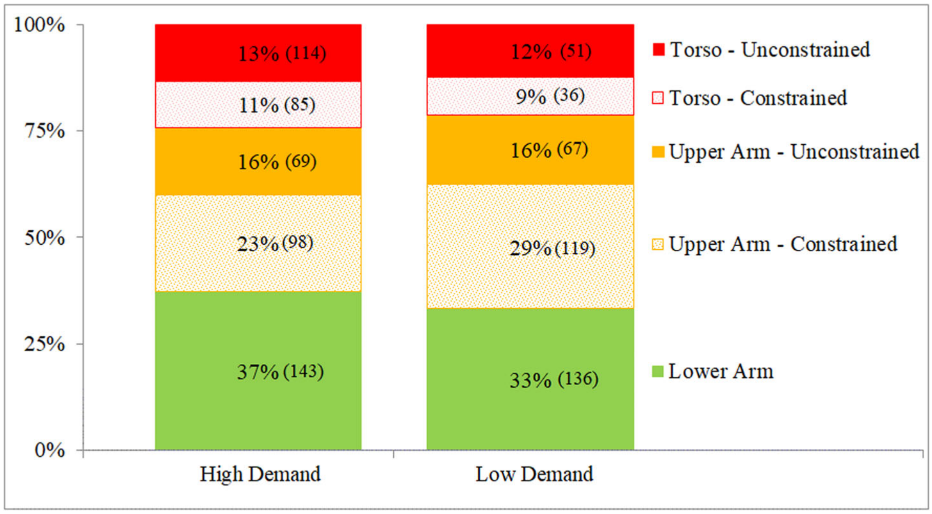


**Figure 6.** Proportion of reaches utilizing the lower arm, the upper arm (constrained and unconstrained), and the torso (constrained and unconstrained) for all subjects (cook and three expediters) during each demand period. The numbers in parenthesis represent the number of reaches for all stations during 75 minutes of observation. Due to rounding, some percentages may not add up to 100%.

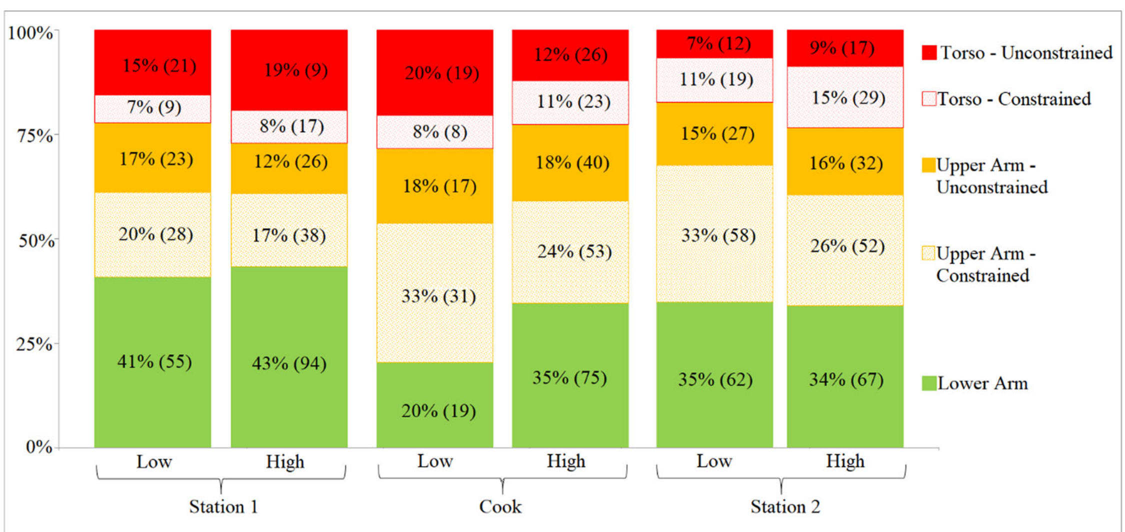


**Figure 7.** Proportion of reaches for all the workers in each station during the period of low demand (transition) and the period of high demand (breakfast). The numbers in parenthesis represent the number of reaches for each worker during 25 minutes of observation. Due to rounding, some percentages may not add up to 100%.

decreased during the period of high demand (22%, SD = 3%) when workers were fulfilling orders. Individually, the expediter in Station 2 had the greatest amount of recovery time independently of demand (Figure 8); 53% (SD = 4%) during low demand (transition), and 37% (SD = 5%) during high demand (breakfast). Recovery time for all of the workers was reduced during breakfast (high demand) time.

### 3.4. Hand Activity Level (HAL)

The greatest HAL (Table 2) occurred during the high-demand breakfast period for both the cook and the expediter in Station 1. The average HAL did not change significantly ($p > 0.05$) for the expediter in Station 2.

## 4. Discussion

### 4.1. Reaching Posture

The proportion of reaching outside the reach envelope (Figure 3), constrained and unconstrained, did not change significantly ($p > 0.05$) as demand decreased (see Figure 6). Overall, reaching outside the reach envelope occurred 63% and 67% during the high and low-demand periods, respectively. Individual analysis

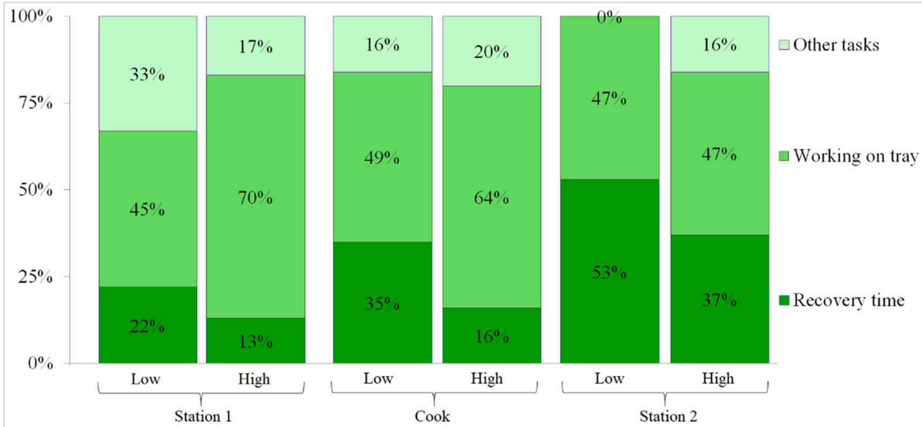


**Figure 8.** Proportion of recovery time (resting, walking, talking, or reading), time spent working on trays, and time spent on other tasks (e.g., restocking) for all workstations during the period of low demand (transition) and high demand (breakfast).

**Table 2.** Mean and 95% confidence intervals for the HAL of each worker in each of the different demand periods.

| Worker | High demand (breakfast) | Low demand (transition) |
|---|---|---|
| Cook | 7.4 [7.2, 7.7] | 5.8 [5.5, 6.0] |
| Expediter – Station 1 | 7.6 [7.3, 7.9] | 5.2 [4.9, 5.5] |
| Expediter – Station 2 | 3.6 [4.2, 3.1] | 3.9 [3.1, 4.6] |

for each station showed no effects on reaching posture for the expediters.

In contrast, the cook had an inverse response to the decrease in demand during the transition time. His proportion of unconstrained torso reaches significantly ($p < 0.05$) increased during the low demand time (by 8%). Further research investigating the drivers of worker decisions to reach in this manner is needed. A possible explanation for increasing unconstrained reaches during the low-demand period may be found when analyzing his recovery time in more detail. During the low-demand period, he had ample recovery time (35%). Of the total recovery time, 30% (10.5% of the total time) was spent on reading ticket orders or walking, activities that did not require the use of his upper extremities but that were still part of his work. The remaining 70% of the recovery time (24.5% of the total time) was spent standing and not doing work-related tasks. On the other hand, during the high-demand breakfast time, when he had 16% recovery time, only 12% (1.9% of the total time) of it was spent standing and not doing work-related tasks. Presumably, having the chance to rest his legs by walking less, the cook chose to increase his proportion of unconstrained reaches using his torso, especially because there were fewer reaches during this time.

This increase in the proportion of unconstrained reaches using the upper arms or torso can be considered an increase in exposure to physical risk factors for WMSDs. However, it is important to consider that, especially during the low-demand period when there was not much pressure to reach using the torso to save time, the cook had control or decision authority (Johnson et al., 1996) over his decision to reach this way. This control may allow him to reduce the psychosocial stress related to the task, and therefore maintain a lower level of risk of developing WMSDs (Andersen et al., 2002; Costa et al., 2010; de Jonge & Kompier, 1997; Punnett & Wegman, 2004; Tsigonia et al., 2009). Even though questions have been raised regarding whether providing workers with job control is always beneficial (Meier et al., 2008), those concerns are related to workers who prefer to have low decision control in situations where they may be blamed by a poor outcome and who are not confident in their abilities to do the job correctly (e.g., deciding which equipment to buy). In a hospital kitchen environment, allowing workers some control over how they choose to reach is likely not detrimental, because their work will not be negatively impacted by their decision to perform a constrained vs. unconstrained reach.

These results indicate that placing frequently used items within reach, allowing for a reduction in the constrained reaches, may be more effective in reducing the proportion of reaching outside the reach envelope than reducing the number of tasks a worker must complete. Workstation layout changes to reduce the need for non-neutral postures have also been suggested by Dareker and Peshave (2016) and Kamat et al. (2017).

### 4.2. Recovery Time

As expected, worker recovery time decreased as customer demand increased. In a self-paced environment, as workers receive more meal orders and get busy fulfilling them, they have less time to rest. Figure 8 shows that station 2 had the greatest recovery time during all work periods (high demand = 37%, low demand = 53%). This workstation was afforded greater recovery time because 94% of the trays include an item prepared by the cooks, leaving this station starved of materials to complete the job. The time spent waiting for meals to be ready provided time for recovery. The expediter in station 1 had the least recovery time (13%) during the high-demand period. The tasks this expediter was assigned did not differ greatly in type or quantity by mealtime. Because this expediter rarely had to wait for the cook, there was not an external influence on her available recovery time.

Traditionally, worker pacing has been studied in manufacturing settings with clearly defined cycle times. For assembly lines with large cycle-to-cycle variations, such as investigated here, self-paced assemblies have long been proposed as a way to improve productivity (Conrad, 1954, 1955a, 1955b; Davis, 1965) and quality (Bosch et al., 2011; Lin et al., 2001) while reducing waste (idle time) in the presence of process time and worker variability. The reduction in idle time has, in turn, been shown to result in reduced recovery time, since workers do not use the advantage of being able to control their pace and recover but instead work continuously with shorter cycle times (Carrasquillo et al., 2017; Dempsey et al., 2010). The workers in this hospital kitchen were self-paced, as they must manually move all the items from the beginning to the end of the conveyor. The results in this study mirror those found in manufacturing settings. The expediter in station 1 and the cook, both of whom worked completely self-paced, experienced a greater reduction in recovery time as the demand increased than the expediter in station 2 whose pacing was limited by the requirement to wait for processing time (cooking). These results show the importance of having some external controls to worker pacing, to ensure workers have sufficient recovery time and that periods of recovery occur more regularly. Having a frequent opportunity for recovery, instead of after long periods of continuous work followed by recovery, may also help reduce the risk of WMSDs without having adverse effects on system performance (Patti & Watson, 2010).

### 4.3. Hand Activity Level (HAL)

As demand decreased and recovery time increased, there was an overall decrease in HAL for the expediter in station 1 and the cook (Table 2). HAL significantly decreased ($p < 0.05$) as demand decreased (HAL decrease for both workers = 2). Both workers repeated motions in the high-level category of HAL as defined by Latko et al. (1999) during the high-demand period, and decreased their motions to a medium level during the low-demand period. Given that the type of work did not change during the different demand periods, it can be assumed that the normalized peak forces remained constant. The reduction in HAL as demand decreased, therefore, suggests a reduction in exposure to physical risk factors of WMSDs (ACGIH, 2016). The coupling of the decrease in HAL and the increase in recovery time further supports a reduced exposure among these workers.

However, the expediter in station 2 was not observed to decrease her HAL even when the demand decreased, and recovery time increased by 16%. On average, her HAL was maintained at a medium HAL level of 4. This expediter was paced by the speed of cooking, as she had to wait for meals to be cooked before putting them on a tray. Thus, even when demand was high, her hands could move food orders only as fast as the cook could have them ready. Therefore, the speed of her hands was limited by material availability. While this expediter had more recovery time during the low-demand period, and the HAL was frequently reduced to 0, it was observed that during the low-demand period she moved her hands faster when she did have orders to fulfill. As a result, she spent four additional minutes at a HAL of 5 or 6 during the low-demand period than during the high-demand period. When the average HAL was calculated, there was a similar average value during both demand periods, regardless of the additional recovery time.

While research studies (Carrasquillo et al., 2017; Conrad, 1954, 1955a, 1955b; Davis, 1965; Dempsey et al., 2010) have shown that workers tend to work continuously and with reduced recovery when they are self-paced, as previously discussed none of the studies evaluated the HAL in this context, and more research is needed to understand which factors may lead workers to move their hands faster than needed. In the current case, it is possible the worker moved faster so that she could have more time for recovery. Expediter 2 had to place completed trays in a cart that often required her to reach below her knees or above her shoulders. This workstation was tasked with the highest force exertion requirements among the observed workers, an observation also noted in another hospital kitchen (Chim, 2006). At the same time, her ability to control the decision of whether to move faster may provide her with some reduction in risk of WMSDs as discussed earlier (Andersen et al., 2002; Costa et al., 2010; de Jonge & Kompier, 1997; Punnett & Wegman, 2004; Tsigonia et al., 2009).

Therefore, the average HAL generally increased as the demand increased, but this effect varied between workstations. These HAL levels demonstrate that the workers in this hospital kitchen may be at increased risk of developing discomfort and WMSDs, because their average HAL did not decrease to low levels even during the transition time when recovery time increased. Latko et al. (1999) demonstrated that repetition alone can be a physical risk factor independent of the loads exerted by workers. Their study showed that 46.5% and 37.1% of the workers they observed with high and medium HAL, respectively, reported symptoms of discomfort in their hands. Only 22.0% of the workers with low HAL (< 3.3) reported the same symptoms, and the trend was similar for tendinitis and carpal tunnel syndrome.

### 4.4. Limitations

This study included only three workers in a hospital kitchen. Worker age, height, mass, and the number of employees required to meet demand may affect the HAL, recovery time, and reaching postures of the workers. It is possible that different workers performing the same tasks on different days would reach outside their reach envelopes at a different frequency, and that their HAL and recovery time would differ as well. All the workers studied were young (<40 years) and had a normal weight as defined by the NIH (BMI < 24.9). Older workers or those who are overweight or obese may perform unconstrained reaches at a lower proportion or may reduce the HAL further during the low-demand periods. Also, the examined workers were of close to average height or taller, whereas workers closer to the $5^{th}$ or $95^{th}$ percentiles in height may have to perform constrained reaches more frequently and may have an increase in HAL and reduce their recovery times as a result. Furthermore, it is possible that in conditions where demand is even greater, and even more workers are present in the hospital kitchen, the reaching postures and frequency of reaching may change as workers have to move past each other while they complete their tasks around the kitchen. Given that only one worker was studied in each workstation, and that it is possible that workers with different characteristics may reach or move in other ways, the interpretation of the statistics is limited outside this case study.

### 4.5. Conclusions

This case study shows that measures developed for assessing exposure to physical risk factors for WMSDs can be meaningfully applied to workers in commercial kitchens. Specifically, as demand increased, recovery time and HAL may decrease and increase, respectively. On the other hand, the frequency of reaching outside the reach envelope did not show a significant effect of changes in demand. Overall, as demand increased, recovery time decreased by 15% and HAL increased by 2 points. Our results also demonstrate the importance of having some form of external pacing controls, to provide workers with more recovery time and prevent increases in HAL with demand increases. Further work should be conducted with a larger worker sample to determine how these results can be applied to the general population. Additionally, given the lack of literature in this area, further work is needed to develop a deeper understanding of the relationshisp between HAL, work demand fluctuations, and pacing, as well as into the underlying reasons that drive workers to perform unconstrained reaches and whether ergonomists should strive to identify countermeasures to reduce their frequency.

## Conflict of Interest

The authors do not have any conflict of interest to report.

## Funding

This research was supported with funds from the NIOSH Pilot Project Research Training Program (PPRTP) and the NIH grants 5T42OH008455-08, 2T42OH008455-09, and 5T42OH008455-10

## ORCID

Vernnaliz Carrasquillo http://orcid.org/0000-0001-8278-4803

## References

ACGIH. (2016). *Threshold limit values for chemical substances and physical agents and biological exposure indices* [Paper presentation]. American Conference of Governmental Industrial Hygienists (2016th ed.).

Alamgir, H., Swinkels, H., Yu, S., & Yassi, A. (2007). Occupational injury among cooks and food service workers in the healthcare sector. *American Journal of Industrial Medicine*, *50*(7), 528–535. https://doi.org/10.1002/ajim.20475

Aminoff, T., Smolander, J., Korhonen, O., & Louhevaara, V. (1999). Physiological strain during kitchen work in relation to maximal and task-specific peak values.

*Ergonomics*, *42*(4), 584–592. https://doi.org/10.1080/001401399185496

Andersen, J. H., Kaergaard, A., Frost, P., Thomsen, J. F., Bonde, J. P., Fallentin, N., Borg, V., & Mikkelsen, S. (2002). Physical, psychosocial, and individual risk factors for neck/shoulder pain with pressure tenderness in the muscles among workers performing monotonous, repetitive work. *Spine*, *27*(6), 660–667. https://doi.org/10.1097/00007632-200203150-00017

Bernard, B. P. (1997). A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back edited. In *Musculoskeletal disorders and workplace factors*.

Bosch, T., Mathiassen, S. E., Visser, B., de Looze, M. D., & van Dieën, J. V. (2011). The effect of work pace on workload, motor variability and fatigue during simulated light assembly work. *Ergonomics*, *54*(2), 154–168. https://doi.org/10.1080/00140139.2010.538723

Carrasquillo, V., Armstrong, T. J., & Hu, S. J. (2011). Work variations and musculoskeletal stresses in paced production operations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *55*(1), 1012–1016. https://doi.org/10.1177/1071181311551211

Carrasquillo, V., Armstrong, T. J., & Hu, S. J. (2017). Effect of cycle to cycle task variations in mixed-model assembly lines on workers' upper body and lower back exertions and recovery time: A simulated assembly study. *International Journal of Industrial Ergonomics*, *61*, 88–100. https://doi.org/10.1016/j.ergon.2017.05.011

Carrasquillo, V., Armstrong, T. J., & Hu, S. J. (2017). Mixed-model assembly lines and their effect on worker posture and recovery time. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *61*(1), 968–968. https://doi.org/10.1177/1541931213601723

Chim, J. (2006, November). *Ergonomics workload analysis for the prevention of musculoskeletal disorders in food services in the health sector* [Paper presentation]. 42nd Annual Human Factors and Ergonomics Society of Australia Conference 2006, HFESA 2006 (pp. 197–205).

Conrad, R. (1954). The rate of "paced" man-machine systems. *Institution of Production Engineers Journal*, *33*(10), 562. https://doi.org/10.1049/ipej.1954.0070

Conrad, R. (1955a). Comparison of paced and unpaced performance at a packing task. *Occupational Psychology*, *29*(1), 15.

Conrad, R. (1955b). Setting the pace. *The Manager (London)*, *23*, 664–667.

Costa, B. R., Vieira, E. R., da Costa, B. R., & Vieira, E. R. (2010). Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *American Journal of Industrial Medicine*, *53*(3), 285–323. https://doi.org/10.1002/ajim.20750

da Luz, C. M., da Costa Proenca, R. P., de Salazar, B. R. O., & do Nascimento Galego, G. (2013). Working conditions at hospital food service and the development of venous disease of lower limbs. *International Journal of Environmental Health Research*, *23*(6), 520–530. https://doi.org/10.1080/09603123.2013.769203

Dareker, S., & Peshave, M. (2016). A Study of importance of kitchen designing in standalone restaurants. *International Journal of Research in IT & Management*, *6*(6), 100–109.

Davis, L. E. (1965). Pacing effects on manned assembly lines. *International Journal of Production Research*, *4*(3), 171–184. https://doi.org/10.1080/00207546508919974

de Jonge, J., & Kompier, M. a. J. (1997). A critical examination of the demand-control-support model from a work psychological perspective. *International Journal of Stress Management*, *4*(4), 235–258. https://doi.org/10.1023/B:IJSM.0000008152.85798.90

Dempsey, P. G., Mathiassen, S. E., Jackson, J. A., & O'Brien, N. V. (2010). Influence of three principles of pacing on the temporal organisation of work during cyclic assembly and disassembly tasks. *Ergonomics*, *53*(11), 1347–1358. https://doi.org/10.1080/00140139.2010.520745

Glina, D. M. R., Cardoso, A. S., Isosaki, M., & Rocha, L. E. (2011). Participatory ergonomics: Understanding the contributions of reflection groups in a hospital food service. *International Journal of Industrial Ergonomics*, *41*(2), 96–105. https://doi.org/10.1016/j.ergon.2010.12.005

Johnson, J. V., Stewart, W., Hall, E. M., Fredlund, P., & Theorell, T. (1996). Long-term psychosocial work environment and cardiovascular mortality among Swedish men. *American Journal of Public Health*, *86*(3), 324–331. https://doi.org/10.2105/ajph.86.3.324

Kamat, S. R., Azalin Nordin, E., Husain, K., Aznee, S., & Ali, S. (2017). Investigation of musculoskeletal disorders among workers in food services (cafeteria). *Human Factors and Ergonomics Journal*, *2*(3), 27–33.

Latko, W. A., Armstrong, T. J., Foulke, J. A., Herrin, G. D., Rabourn, R. A., & Ulin, S. S. (1997). Development and evaluation of an observational method for assessing repetition in hand tasks. *American Industrial Hygiene Association Journal*, *58*(4), 278–285. https://doi.org/10.1080/15428119791012793

Latko, W. A., Armstrong, T. J., Franzblau, A., Ulin, S. S., Werner, R. A., & Albers, J. W. (1999). Cross-sectional study of the relationship between repetitive work and the prevalence of upper limb musculoskeletal disorders. *American Journal of Industrial Medicine*, *36*(2), 248–259. https://doi.org/10.1002/(SICI)1097-0274(199908)36:2 < 248::AID-AJIM4 > 3.0.CO;2-Q

Lin, L., Drury, C. G., Kim, S., & Hall, B. (2001). Ergonomics and quality in paced assembly lines. *Human Factors and Ergonomics in Manufacturing*, *11*(4), 377–382. https://doi.org/10.1002/hfm.1020

Matsuzuki, H., Haruyama, Y., Muto, T., Aikawa, K., Ito, A., & Katamoto, S. (2013). Workers' load and job-related stress after a reform and work system change in a hospital kitchen in Japan. *Environmental Health and Preventive Medicine*, *18*(2), 171–176. https://doi.org/10.1007/s12199-012-0291-9

McAtamney, L., & Corlett, E. N. (1993). RULA: A survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics*, *24*(2), 91–99.

Meier, L. L., Semmer, N. K., Elfering, A., & Jacobshagen, N. (2008). The double meaning of control: Three-way interactions between internal resources, job control, and stressors at work. *Journal of Occupational Health Psychology*, *13*(3), 244–258. https://doi.org/10.1037/1076-8998.13.3.244

Moatari-Kazerouni, A., Chinniah, Y., & Agard, B. (2015a). A proposed occupational health and safety risk estimation tool for manufacturing systems. *International*

*Journal of Production Research*, *53*(15), 4459–4475. https://doi.org/10.1080/00207543.2014.942005

Moatari-Kazerouni, A., Chinniah, Y., & Agard, B. (2015b). Integration of occupational health and safety in the facility layout planning, part II: Design of the kitchen of a hospital. *International Journal of Production Research*, *53*(11), 3228–3242. https://doi.org/10.1080/00207543.2014.970711

National Academy Press, Washington, DC. (2001). *National Research Council, The Institute of Medicine. Musculoskeletal disorders and the workplace: Low back and upper extremities.*

NIST/SEMATECH. (2013). *7.4.7.4. Comparing multiple proportions: The Marascuillo procedure*. https://www.itl.nist.gov/div898/handbook/prc/section4/prc474.htm

Patti, A. L., & Watson, K. J. (2010). Downtime variability: The impact of duration-frequency on the performance of serial production systems. *International Journal of Production Research*, *48*(19), 5831–5841. https://doi.org/10.1080/00207540903280572

Punnett, L., & Wegman, D. H. (2004). Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. *Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology*, *14*(1), 13–23. https://doi.org/10.1016/j.jelekin.2003.09.015

Tseng, M., & Hu, S. J. (2014). CIRP encyclopedia of production engineering. *The International Academy of Production Engineering*, 836–837.

Tsigonia, A., Tanagra, D., Linos, A., Merekoulias, G., & Alexopoulos, E. C. (2009). Musculoskeletal disorders among cosmetologists. *International Journal of Environmental Research and Public Health*, *6*(12), 2967–2979. https://doi.org/10.3390/ijerph6122967