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Novel Noise Monitoring Prototypes to Measure the Impact of Two-way Radio Earpiece Noise

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Abstract

Current noise exposure measurement techniques fail to account for the noise emitted from a two-way radio earpiece and are impractical for highly variant and physically demanding work environments. Two novel prototypes were created to adapt a standard noise dosimeter for measuring noise levels when a two-way radio earpiece was used.

The first prototype was an attachment that fit over the microphone of a noise dosimeter and led up to the earpiece using acoustic tubing. The second prototype included a microphone in the earpiece. The two prototypes were laboratory tested using a mannequin system. When compared to the dosimeter equivalent, the corrected microphone prototype was more accurate than the corrected attachment prototype, with a mean difference of -0.2 dBA and -6.9 dBA, respectively. However, both were relatively consistent with the standard deviations of the difference between the corrected prototype and dosimeter equivalents being 0.76 dBA and 1.26 dBA, respectively.

The prototypes were used in a mechanized sorting facility and with police officers to measure the effect of using a two-way radio earpiece. In the sorting facility with ambient noise above 80 dBA, using an earpiece was protective, with measurements 3.6-7.9 dBA less than the levels measured when a two-way radio shoulder mounted speaker was worn instead. During the traffic stop scenario, the prototypes identified that wearing an earpiece appeared to be protective for the contact officer while it caused more noise for the cover officer, with mean noise levels of 8 or 12 dBA above the standard dosimeter.

Introduction

To facilitate communication and safety during occupational tasks, workers such as first responders, active-duty service members, construction workers, and industrial workers may utilize an earpiece attached to a two-way radio. First responders have an increased risk for noise-induced hearing loss (NIHL) (Lesage, Jovenin, Deschamps, & Vincent, 2009; Ide, 2011). However, their measured average exposures over a shift don't always exceed the Occupational Safety and Health Administration (OSHA) action level (Tubbs, 1995; Gilbertson & Vosburgh, 2015). One explanation for the increased risk of NIHL may be the additional noise exposure that results from the use of a two-way radio with an earpiece.

The cause of the increased risk for NIHL among occupations using two-way radios with earpieces is difficult to discern. First, radio noise is unpredictable, transient, and varies acoustically from one instance to the next depending

on communication needs and occupational tasks. Second, radios allow for adjustment of settings to accommodate background noise and listening preference, which varies across individuals (Keith, Michaud, & Chiu, 2008). Radio communication may need to be 2-15 dB above the ambient noise level for clear communication (Killion, 2002; Giguère, Behar, Dajani, Kelsall, & Keith, 2012). Individuals listening in noisy settings may increase the radio setting above the occupational damage risk criteria (Muchnik, Amir, Shabtai, & Kaplan-Neeman, 2012). Lastly, standard methods of noise dosimetry cannot measure the contributions of two-way radios.

A body of work exists evaluating noise exposure contributions from communication systems. Documented methods include the use of acoustical test fixtures, head and torso simulators, microphones in real ears, and indirect calculations (Dajani, Kunov, and Seshagiri, 1996; Giguère et al., 2012; Kunov, Giguere, &Simpson, 1989). A set of standards were developed to guide these methods of measurement (ISO, 2002; ISO, 2004; OSHA, 2013). Research teams utilized silicone tubing attached to a custom ear mold, measured voltage output of sound-generating devices, and utilized a small in-ear electronic microphone in the experimental setup in attempts to better measure noise from headsets and earpieces attached to sound-generating devices (Brammer, Yu, Bernstein, Peterson, Cherniack, & Tufts 2009; Muchnik et al., 2012; Shotland, 1996; Portnuff, Fligor, & Arehart 2013; Nélisse, Le Cocq, Boutin, Laville, & Voix 2015). However, these methods have not resulted in an affordable, portable, or practical option that can account for individual differences across employees as they actively navigate physically demanding work environments while using two-way radio earpieces for communication. This paper describes two novel prototype designs to support further development of affordable, portable noise monitoring devices for industry workers and first responders.

Research Methods

Prototype Designs

Two prototypes, attachment and microphone, were created as suitable options for measuring two-way radio exposure with an earpiece (U.S. Patent No. 10,560,776, 2020). The attachment prototype (Figure 1A) was designed to be simple with low costs associated with fabrication. The attachment prototype connected acoustic tubing from the dosimeter (Edge 5, 3M, St. Paul, MN, USA) microphone to the earpiece (Otto Engineering C101199-05 Quick Disconnect Acoustic Tube with Clear Eartip, OTTO Communications, Carpentersville, IL, USA). A plastic splitter in the shape of a "T" replaced the standard L-shaped connector that fit into a hole in the earpiece. The change in connector resulted in negligible changes in frequency response. The original acoustic tubing (C101199-5, OTTO Communications, Carpentersville, IL, USA) was connected to one arm of the T and then connected to the radio as normal. A second piece of acoustic tubing was attached to the other arm of the T and led to a hard plastic cover that slipped over the microphone of the noise dosimeter (Edge 5, 3M, St. Paul, MN, USA), after the windscreen was removed.

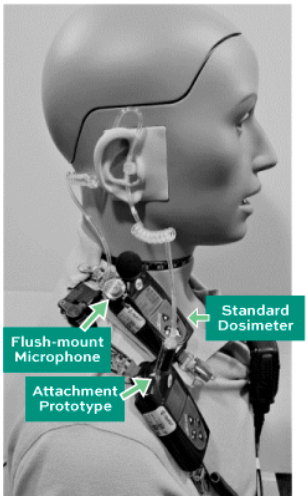
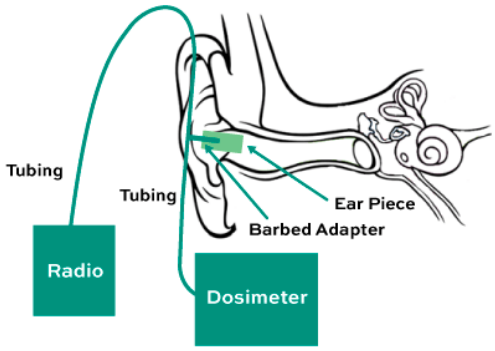


Figure 1A - Attachment Prototype



The microphone prototype design was more technologically advanced than the attachment prototype. For the microphone prototype (Figure 1B), the microphone on the noise dosimeter (Edge 5, 3M, St. Paul, MN, USA) was removed and a top-port micro-electro-mechanical systems (MEMS) (Invensense INMP510 Micro-Electrical-Mechanical System, dynamic range = 91 dB, frequency response= 0.06-20kHz) microphone was attached to the earpiece with silicone adhesive and a silicone retaining ring and wired to the noise dosimeter. The supply voltage and input signal to trigger calibration mode necessitated the design of a new circuit for the purpose of operating the MEMS microphone and amplifying its output to an appropriate level to interface with the existing circuit.

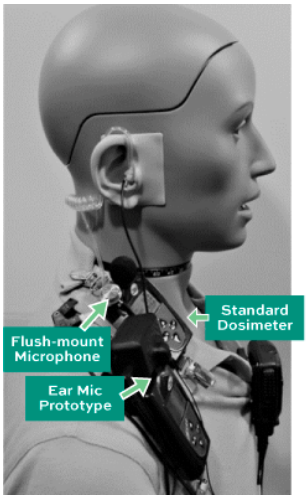


Figure 1B - Microphone Prototype

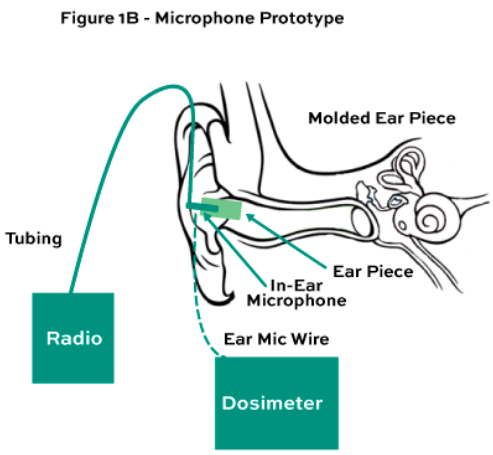


Figure 1B - Microphone Prototype

Due to design differences, the two prototypes did not respond the same to ambient noise and radio noise. When radio noise was transmitted through the tubing, it created resonant frequencies above 3,000 Hz. The resonance was similar to how acoustic tubing significantly influences mid-and high-frequency gain on hearing aids by the standing wave resonances within the tubing, causing additive or destructive interference at multiple frequencies (Taylor & Teter, 2009). Since the prototypes did not make significant changes to the mathematical calculations that were already programmed into the dosimeters, a two-step correction was needed to adjust the data the prototype collected only when noise was transmitted through the radio. Step one was to determine the mathematical equations to modify the one-minute measurements the prototype recorded. Because two-way radios are used intermittently throughout a work shift, the mathematical correction could not be applied across all one-minute measures. Step two identified which one-minute measurements required the mathematical correction when the two-way radio was in use.

Prototype Correction Step One

Laboratory Set-Up

Step one of the prototype correction occurred in a double-walled audiology booth with a mannequin system (KEMAR 45BC-2 Head & Torso with Mouth Simulator with Shore 00-55 Left and Right Ears, GRAS Sound & Vibration, Holte, Denmark). Data were digitized with a data acquisition system (SIRIUS MINI, Dewesoft, Trbovlje, Slovenia) connected to a laptop running data acquisition software (DewesoftX3, Dewesoft, Trbovlje, Slovenia). The internal mannequin microphone collected 1/3 octave band spectral data of the noise in the mannequin's ear. The internal mannequin microphone results were converted into dosimeter equivalent noise levels using the ISO Standard 11904-2 (ISO 2004) for diffuse field so results could be compared to the prototype and standard dosimeter. For testing, three noise measurement devices (a prototype, a standard dosimeter, and a flush-mount microphone) were placed on the mannequin (Figure 1A and 1B). Either an attachment prototype or microphone prototype was placed on the mannequin. A standard dosimeter (Edge 5, 3M, St. Paul, MN, USA) was placed on the right shoulder of the mannequin next to the prototype dosimeter to measure the ambient

noise in the room and represented the standard measure of noise exposure. A flush-mount microphone (47AD 1/2" CCP Flush-mount Microphone Set, GRAS Sound & Vibration, Holte, Denmark) was placed on the standard dosimeter, so the microphone was as close as possible to the standard dosimeter microphone and was connected to the data acquisition system. The flush-mounted microphone measured 1/3 octave band spectral data to serve as a quality control measure of ambient noise levels.

The standard dosimeter and the prototypes were programmed to have A-weighting, three-decibel exchange rate, 130 dB upper limit, and no threshold. All dosimeters were pre-calibrated and post-calibrated with a noise dosimeter calibrator (QC-10, 3M, St. Paul, MN, USA). A custom calibrator attachment was created for the microphone prototype so that it fit the appropriate location in the calibrator during calibration.

Two radio units (TK-5220, Kenwood Communications, Suwanee, GA, USA) were used during testing. One radio unit was clipped to the mannequin shirt waist and connected to the prototype. The earpiece was fit into the right ear of the mannequin for all tests. The partner radio remained outside the booth and served as the input for radio noise.

Pink noise served as the source of noise through the radio. To send pink noise through the radio, pink noise was emitted from an iPad (3rd generation iPad, Apple, Cupertino, CA) using the Audio Function Generator Pro application and transmitted to the two-way radio hand-held microphone outside of the sound booth. Every 30 seconds, the hand-held radio microphone key was released and then depressed again to avoid the warning beep that discharged from the hand-held radio microphone, if keyed for more than one minute.

Mathematical Equations

Tests were conducted to determine the relationship between the prototype measurements and the dosimeter equivalent values. The same test was conducted for both prototypes. Testing started with the radio connected to the prototype set so the prototype was measuring a level of at least 80 dBA. The radio setting was then increased by approximately three decibels for each subsequent measurement. Each decibel level was measured for three minutes. This continued until the radio setting was at 100%. Linear regression was then used to determine the relationship between the raw prototype decibel levels and the dosimeter equivalent levels (Figure 2). Equations 1 and 2 represent the attachment and microphone prototypes, respectively, where Lraw_attach is the raw prototype decibel level for the attachment prototype, and Lraw_mic is the raw prototype decibel level for the microphone prototype. Lcorr_attach is the corrected prototype decibel level for the attachment prototype, and Lcorr_mic is the corrected prototype decibel level for the microphone prototype.

Lcorr_attach=1.0448Lraw_attach-43.9 [1]

Lcorr_mic=1.0372Lraw_mic-27.6 [2]

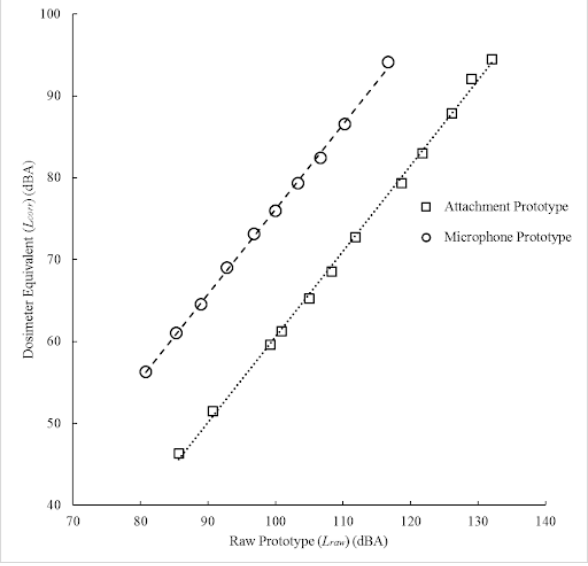


Figure 2: Relationship between prototype and dosimeter equivalent levels

Correction Step One Laboratory Testing

Equations 1 and 2 were tested in the laboratory using the laboratory setup. Each prototype was tested at 50% and 100% radio setting, with and without ambient noise. Pink noise served as the source of noise through the radio and as the ambient noise source during laboratory testing. The ambient pink noise played in the sound booth 90 degrees azimuth to the mannequin over a portable speaker (Jam Plus Portable Speaker HX-P240GY, Frequency Response: 0.1-18 kHz, Jam Audio, Commerce Township, MI, USA) attached to an iPad (3rd generation iPad, Apple, Cupertino, CA) using the Audio Function Generator Pro application. The ambient noise decibel level was set to approximately 80 dBA as measured by the standard dosimeter. Testing was completed over multiple days so there was variability in the ambient noise level. Approximately 80 dBA were chosen because it was a level that could be found at a workplace that could interfere with communication, justifying the use of the radio, but would not require the use of hearing protection. To send pink noise through the radio, pink noise was emitted from an iPad and transmitted to the two-way radio hand-held microphone outside of the sound booth. Every 30 seconds, the hand-held radio microphone key was released and then depressed again to avoid the warning beep that discharged from the hand-held radio microphone if keyed for more than one minute. Each condition was measured for three minutes, and each condition was measured three times.

Prototype Correction Step Two

The correction was not designed to be applied to the time-weighted average (TWA) of the exposure but instead to only the individual one-minute measurements when the radio was transmitting. Step two of the correction identified which one-minute prototype measurements required the mathematical correction.

The raw prototype one-minute measurements are noticeably greater than the standard dosimeter one-minute measurements when noise is being transmitted through the radio in an environment with ambient noise levels less than 80 dBA. However, in work environments where ambient noise levels are 80 dBA and greater, or the environment is highly variable, identifying when the radio is used is not obvious because the dosimeters used in this study averaged decibel levels over one minute. In these more challenging workplaces, a difference value must be used to help identify when the difference is a real difference or just a result of the minute averaging of the dosimeters.

To determine the difference value, the prototypes were taken into an industrial setting with ambient noise close to 80 dBA. The work setting was chosen so that identifying the difference value would be a challenge of the prototypes, but wouldn't require the workers to wear hearing protection, which the two-way radio earpiece was not verified to provide.

Both prototypes were brought into a mechanical sorting facility. The facility was a large building with the majority of the area dedicated to mechanical sorting using conveyors. Offices were located in a small central portion of the sorting floor as well as on one side of the building. The conveyors were only used during the sorting period of a shift, which lasted between three to five hours depending on the amount of material being sorted. Laborers and managers at the facility wore two-way radios during sorting to communicate due to the size of the facility and the ambient noise levels (greater than 80 dBA) produced by the conveyors. Laborers stayed in the sort area. Managers moved through the entire facility.

Two managers wore a prototype, one wore an attachment and one wore a microphone, and a standard dosimeter (Edge 5, 3M, St. Paul, MN, USA) for the first two hours of a sort while completing their normal activities. During the two hours, a third radio at 100% radio setting was put in a quiet room where there were no other noise sources above 80 dBA, with an additional Edge dosimeter (Edge 5, 3M, St. Paul, MN, USA). All dosimeters were programmed to American Conference of Governmental Industrial Hygienists (ACGIH) specifications of A weighting, 3 dB exchange rate, and 80 dB threshold (Berger, 2003). By enabling the 80 dBA threshold, the recorded one-minute measurements showed when noise was

transmitted through the radio. Whenever there was not a transmission through the radio, the dosimeter in the room recorded a value of 0.00 dBA. When a transmission was sent through the radio, the noise in the room increased to over 80 dBA so a number greater than 0.00 was recorded.

The five dosimeters were started as close as possible to the same starting time. The microphone prototype and associated standard dosimeter were started 19 seconds after the room dosimeter. The attachment prototype and associated standard dosimeter were started 10 seconds after the room dosimeter. The manager who wore the attachment prototype needed to have the prototype adjusted so the prototype was paused for five minutes during the two hours. After the two hours were complete, the dosimeter and prototypes were downloaded as one-minute measurements and the data was analyzed.

Data Analysis

First, the number of one-minute measurements from the room dosimeter that were anything other than 0.00 dBA were summed to find the total number of minutes the radio was used. Then, the one-minute measurements for each workers' standard dosimeter (Li_standard) and prototype (Li_prototype) were matched by the time stamp. The differences (Di) of each minute i were calculated using equation 3.

$$Di = Li\_prototype - Li\_standard \quad [3]$$

The number of minutes where Di was greater than the tested difference value was summed and then divided by the total number of minutes the radio was used. Six values to be compared to Di as the difference values were: 8 dBA, 9 dBA, 10 dBA, 11 dBA, 12 dBA and 13 dBA. A percentage of the correctly identified minutes was compared for each difference value.

The total number of minutes the radio was used over the two-hours was 80 minutes. The minute volume levels measured when a transmission was sent through the radio varied from 59.9 dBA to 94.2 dBA. Every minute value of the dosimeter was averaged over the 60 seconds of the minute. Therefore, if a comment through the radio did not last for a full minute, the decibel value for the minute recorded by the dosimeter was less than the threshold value of 80 dBA. The range of decibel levels showed that some radio transmission noise lasted for less than a minute while others lasted for the full minute.

The test values to compare to Di are shown in Table 1. The test value of 10 dBA had the largest percentage without the percentage exceeding 100%, so it was chosen as the difference value.

Table 1: Difference Values Tested

Difference Values (dBA)	Attachment Prototype	Microphone Prototype
8	92.5%	121.3%
9	92.5%	107.5%
10	91.3%	91.3%
11	88.8%	76.3%
12	88.8%	58.8%
13	85%	48.8%

Table 1: Difference Values Tested

Workplace Trials

Both prototypes were utilized at two workplaces. The first workplace was the mechanical sorting facility where step two of the correction was completed. Radios were only worn while sorting occurred, so exposures were only measured during the sorting period. Hearing protection was not provided by the facility for any of the workers. Participants included four laborers and four managers (one female and seven males) ages 20–59 years (mean 31.7 years). One laborer and one manager dropped out during the course of the field trial. When using a two-way radio during a sorting shift, the workers either wore a radio with a prototype or the worker wore a radio with a shoulder-mounted radio speaker. Three shifts were measured for each worker and a different radio configuration was randomly assigned to each shift (standard dosimeter and attachment prototype, standard dosimeter and microphone prototype, or standard dosimeter with a second standard dosimeter on the same shoulder as a shoulder-mounted radio speaker).

The second workplace was a university campus where police officers wore the prototypes during a training traffic stop scenario. The ambient noise during the scenario was less than 80 dBA. The scenario was conducted where a large parking lot and campus streets intersected, and civilian traffic was restricted. Four officers (one female and three males) were involved in the scenario. One officer served as the contact officer. A second served as the cover officer. A third officer occupied and operated the suspect vehicle. The fourth officer served as the dispatcher. The scenario started with the contact and cover officers in the marked squad conducting stationary radar in the campus parking lot. The officers visually identified a speeding suspect vehicle and activated the wail siren. It took approximately one block to stop the suspect vehicle. The contact officer approached the driver side while the cover officer remained at the rear passenger corner of the suspect vehicle. The scenario included routine practices for interacting with dispatch, officers, and suspects. The contact and cover officers conducted the scenario three times with each prototype.

For both workplaces, all the dosimeters and prototypes were programmed to ACGIH specifications. Before any measurements were collected, each participant completed a hearing screen (Earscan 3 Manual Audiometer ES3M, Micro Audiometrics Corporation, Murphy, NC). Sound levels in testing locations met the American National Standard Criteria for maximum permissible ambient noise levels for audiometric test rooms (ANSI, 1999). Three of the participants did not pass the hearing screen in one ear. All participants self-reported normal hearing. All participants were instructed to select the radio setting normally used during a shift. After participants wore the prototypes, they were given a questionnaire asking about comfort and fit.

Results

Correction Step One Laboratory Testing

Table 2 shows the results of the correction step one laboratory testing. When compared to the dosimeter equivalent, the corrected microphone prototype was more accurate than the corrected attachment prototype with a mean difference of -0.2 dBA and -6.9 dBA, respectively. However, both corrected prototypes were consistent across tests with the microphone prototype standard deviation of 0.76 dBA and the attachment prototype standard deviation of 1.26.

Table 2: Results of Correction Step One Laboratory Testing

Radio Setting	Ambient Noise	Standard Dosimeter (dMA)	Raw Prototype (dMA)	Corrected Prototype (dMA)	Dosimeter Equivalent	Difference Between Corrected Prototype and Dosimeter Equivalent
ATTACHMENT PROTOTYPE						
50%	No	60.6[b]	106.7	67.6	72.7	-5.1
100%	No	60.9[b]	126.3	88.0	95.2	-7.1
50%	Yes[a]	79.6[b]	108.3	69.2	77.0	-7.8
100%	Yes[a]	77.0[b]	125.4	87.1	94.8	-7.7
MICROPHONE PROTOTYPE						
50%	No	60.6[b]	98.6	74.7	73.8	0.9
100%	No	61.3[b]	117.8	94.6	94.9	-0.3
50%	Yes[a]	82.3	96.6	72.6	73.2	-0.6
100%	Yes[a]	82.3	115.9	92.7	93.4	-0.8

Note: Flush-mounted microphone measurements were only for verifying quality control and are not shown.
[a]The ambient noise used was pink noise.

Table 2: Results of Correction Step One Laboratory Testing

Workplace Trials

Sorting Facility

The descriptive data from the sorting facility are shown in Table 3. Statistical significance was not calculated due to the small sample size. The mean standard dosimeter measured noise exposure was similar for both managers (85.7–87.0 dBA) and laborers (85.7–87.4 dBA). The corrected prototypes measured differences less than 2 dBA from the standard dosimeter. The corrected prototype levels were 3.6–7.9 dBA less than the shoulder speaker.

Table 3: Results of Workplace Trial at the Sorting Facility

Worker Role	Mean dBA Standard Dosimeter (SD)	Mean dBA Corrected Prototype (SD)	Prototype
Managers	85.7 (1.9)	84.1 (3.0)[a]	Attachment
	85.5 (1.8)	85.4 (2.1)	Microphone
	87.0 (1.3)	89.9 (2.9)[b]	None
Laborers	85.7 (1.8)	83.8 (2.3)[a]	Attachment
	87.3 (3.0)	88.1[c]	Microphone
	87.4 (2.4)	91.7 (1.6)[b]	None

[a] One manager and one laborer asked to remove the attachment prototype during the trials because it was too uncomfortable.
[b] Workers wore a shoulder mounted two-way radio speaker with a second standard dosimeter. The measures under corrected prototype dosimeter reflected the measures of the second standard dosimeter placed near the mounted speaker.
[c] Two laborers did not have their radio turned on during testing of microphone, so there is no SD.

Table 3: Results of Workplace Trial at the Sorting Facility

When surveyed, one participant reported tinnitus after the shift. All participants self-reported 100% radio setting for the majority of their shift and a preference for the microphone prototype. Participants that wore the attachment prototype indicated that the earpiece required readjusting two to three times during the shift. One laborer and one manager requested to remove the attachment prototype because it was uncomfortable and interfered with work.

Traffic Stop Scenario

The descriptive data from the traffic stop scenario are shown in Table 4. Statistical significance was not calculated due to the small sample size of n=3. Both officers adjusted their radio setting during the scenarios. The contact officer preferred a radio setting around 50%, while the cover officer preferred a radio setting near 100%. The contact officer experienced higher mean standard dosimeter levels than the cover officer. Both prototypes identified that the cover officer measured corrected prototype mean noise levels of 8 or 12 dBA above the standard dosimeter. Both officers preferred the microphone prototype over the attachment prototype for comfort and usability.

Table 4: Results of Field Traffic Stop Scenario

Worker Role	Mean dBA Standard Dosimeter (SD)	Mean dBA Corrected Prototype (SD)	Prototype
Contact Officer	68.8 (2.9)	62.3 (8.6)	Attachment
Contact Officer	75.2 (2.6)	74.6 (2.0)	Microphone
Cover Officer	66.6 (1.2)	79.1 (3.2)	Attachment
Cover Officer	67.2 (5.6)	75.5 (0.8)	Microphone

Table 4: Results of Field Traffic Stop Scenario

Discussion

The previously documented and standardized methods for measuring noise exposure in occupational settings with two-way radio communication are limited, and consultants with the equipment capabilities to follow the standard recommendations are sparse. This pilot work indicated that the prototypes may fill the noise measurement need and, with refinement, may serve as an affordable option for measuring two-way radio noise exposure from an earpiece in unpredictable and physically demanding work environments.

Which prototype an individual would select would depend on needs and resources. The microphone prototype was the most accurate and comfortable. Unless safety professionals are comfortable with electrical and mechanical engineering tasks, this prototype serves more as a model for fabrication by a noise dosimeter manufacturer as a potential adaptation to an existing product. The attachment prototype was not as accurate, but it was less expensive and most intuitive to fabricate. It required access to a 3-D printer and purchase of extra tubing and adhesive. Given that the attachment was not as accurate, individuals who use this prototype would want to consider the 6.9 dBA difference from corrected levels when interpreting results. Even so, the attachment would be an inexpensive option for exploring a noise issue before hiring a consultant.

In addition to illustrating the prototype potential for measuring noise in an earpiece caused by a two-way radio, the data presented highlights the importance of measuring three interacting variables when considering noise exposure from two-way radios: ambient noise, radio setting preference, and percentage of radio communication for a given occupational task. Table 3 shows that at the sorting facility with higher levels of ambient noise, the radio earpiece appeared to be protective in the ear that it is worn. High levels of ambient noise combined with high levels of radio use with a shoulder-mounted radio speaker led to the highest risk of increased noise exposure. The data from the traffic stop scenario (Table 4) emphasizes the influence of personal radio setting preference and occupational tasks. The contact officer, with a lower

radio setting preference, experienced higher levels of ambient noise positioned closer to the suspect vehicle and relied more heavily on verbal communication with the suspect. The cover officer, with a higher radio setting preference, was further from the vehicle noise and relied more heavily on radio communication with the contact officer and dispatch. These noted differences in listening preferences and occupational tasks may explain variations in hearing health.

It is important to recognize that this pilot study had a small sample size and limited testing conditions. The current project evaluated a single source of ambient and radio noise in the laboratory. In the field, only two occupational settings were evaluated with a small set of workers. The prototypes, like the standard noise dosimeter used in this study, do not collect 1/3 octave band spectral information, making it difficult to calculate the dosimeter equivalents without assuming the laboratory data mirrors the field data. Additionally, the dosimeters only capture data in one-minute intervals. Radio communication does not necessarily take the entire minute. In order to generalize the results of this pilot study, future work should include a more robust sample size and investigate a wider range of test conditions. A collaborative partnership with an existing dosimeter manufacturer would likely improve the prototype design and result in a more affordable market-ready solution.

Conclusion

The prototypes were able to explore the impact of two-way radio communication on noise exposure in unpredictable and physically demanding work environments. The microphone prototype was more accurate and comfortable, while the attachment prototype was simpler and affordable to create. When determining the impact two-way radio communication has on hearing health, the results encourage measuring the intersection of radio setting preference, ambient noise, and amount of time a radio is used during an occupational task.

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The Association of Gender, Book Bag Style, and Back Pain Among University Students

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Abstract

The purpose of this cross-sectional study is to identify risk factors associated with book bag carriage among college students and discuss strategies for prevention. A nine-question survey and demographic form was administered to study respondents (n= 222). Forty six percent of respondents reported pain in the shoulders, and 37% of respondents reported pain in the lower back. The data shows that of the effective 222 respondents, almost 62% reported pain. Thirty percent of respondents reported pain at multiple locations of the body followed by 14% shoulder and 12% lower back pain. The range for book bag carriage weight was 2.5 lbs. to 25 lbs. Style of book bag, respondent gender, and book bag weight were determinates for self-reported pain. There are several significant findings associated with the study. Female respondents self-reported pain at a higher rate than males. A chi-square test was used to determine whether there is a significant difference between self-reported pain by respondent gender. The difference between these variables was significant, $\chi 2 (1, N = 222) = 8.2019$, $p= 0.0042$. These results suggest that risk factors such as gender, weight, and style of book bag may play a role in self-reported back pain among college students.

Introduction

The purpose of this cross-sectional study is to identify risk factors associated with book bag carriage among college students and discuss strategies for prevention. A nine-question survey and demographic form was administered to study respondents (n= 222). Forty six percent of respondents reported pain in the shoulders, and 37% of respondents reported pain in the lower back. The data shows that of the effective 222 respondents, almost 62% reported pain. Thirty percent of respondents reported pain at multiple locations of the body followed by 14% shoulder and 12% lower back pain. The range for book bag carriage weight was 2.5 lbs. to 25 lbs. Style of book bag, respondent gender, and book bag weight were determinates for self-reported pain. There are several significant findings associated with the study. Female respondents self-reported pain at a higher rate than males. A chi-square test was used to determine whether there is a significant difference between self-reported pain by respondent gender. The difference between these variables was significant, $\chi 2 (1, N = 222) = 8.2019$, $p= 0.0042$. These results suggest that risk factors such as gender, weight, and style of book bag may play a role in self-reported back pain among college students.

The cross-sectional study examined the following research hypotheses (null hypothesis).

1. There is no difference in perceived self-reported pain based on respondent gender
2. There is no difference in respondent perceived self-reported pain, style of book bag
3. There is no difference between on-campus and off-campus respondents reporting of perceived pain

Concerns have often been raised by parents, researchers, and health professionals over heavy book bags carried by children and young adults. These problems may be a significant factor in the development of young adults and may place them at greater risk of ergonomic-related disorders (Pascoe, et al., 1997). However, little is known regarding the

association between college-aged students and risk factors associated with injury due to book bag carriage. Every day, thousands of students carry book bags and purses filled with books, bottles of water, laptop computers, and other items that may create a strain on their bodies. In 1999, the use of book bags resulted in more than 6,000 injuries in the U.S. (Hamilton, 2001). The adverse effects of book bag weight carriage are well documented. In a study performed in 1997, the mean weight of school book bags was 17% of the student's mean body weight, and researchers found that the most common symptoms reported in the study were muscle soreness, back pain, numbness, and shoulder pain (Pascoee, Pascoee, Wang, Shim, 1997).

Previous studies have suggested that book bags of 10% of individual body weight are a justified limit based on epidemiological, physiological, and biomechanical approaches (Brackley, Stevenson, 2004). However, this percentage is specific to young children only and lacks consideration of other factors such as book bag design, the increasing prevalence of obesity among the younger population, and distance and period of carrying the book bag. A survey of 1,178 students in France also concluded that the habitual or prolonged carriage of excessive loads might result in lower back pain and musculoskeletal disorders (Troussier, Davoine, De Gaudemaris, 1994).

Moreover, 35% of respondents in a 2005 survey reported the prevalence of lower back musculoskeletal symptoms, even though the mean weight of school bags was 11.7% of body weight (Whittfield J, Legg SJ, Hedderley DI, 2005). Based on previous studies, researchers contend that the prolonged carrying of heavy loads in book bags could lead to symptoms of body soreness, aches, pains, and tiredness (Johnson, Knapik, 1995). Researchers have found a strong correlation between the loads carried in book bags and lower back symptoms. In recent years, a number of studies have investigated physiological and biomechanical responses to load carriage. In one study, a significant increase in oxygen uptake, energy expenditure, and heart rate were associated with excessive load carriage (Hong, Li, Wong, Robinson, 2000).

Research Methods

The cross-sectional study was approved by the Indiana University's Institutional Review Board. The research design of the descriptive and inferential correlation cross-sectional study examined five (Table 2) different research hypotheses. Specifically, each null hypothesis was tested using an independent t-test, chi-square test, and Fisher's exact test for significance at the .05 level to test the following research null hypotheses:

1. There is no difference in reported pain by respondent gender
2. There no difference in respondent perceived self-reported pain by style of book bag among students who reported pain in one specific location

Study population and instruments:

Study respondents were both undergraduate and graduate students enrolled at Indiana University. Researchers collected data on four different days to complete the study. Study instrument: The respondents (n=222) were requested to complete a demographic form and questionnaire. The sample size of the study is a limitation and further research is needed.

The response rate for the study was 89%. The questionnaire and demographic form included 10 items that surveyed respondents' self-reported pain, location of pain on the body (upper back, lower back, shoulder, neck) frequency of carriage (Monday, Tuesday, Wednesday, Thursday, Friday), style of bag (single strap, double strap, messenger bag), year in school, gender, residence (living on- or off-campus), and frequency of carriage. A Rapala handheld digital scale was used to weigh each book bag and book bag. The electronic scale was calibrated at zero before each respondent's book bag was weighed. The scale weighs to the nearest ounce up to 50 pounds on an LCD screen. Researchers weighed the load carriage of each respondent's bag.

Limitations

The survey instrument required self-reporting and was completed in the presence of researchers. This cross-sectional approach collects data at one time. can be difficult to predict the outcome and the presence of researchers can influence respondents' thoughts, ideas, and responses to questions (Dooley, 1995). The researcher recognizes the need to utilize a validated scale to measure pain. However, since this is a pilot study and the sample size was limited, the researchers considered using a validated pain intensity scale for future studies. According to other researchers, there may be limitations associated with self-reported pain intensity scales in terms of individualized pain tolerances and genetic predisposition to pain perception. There is also biological evidence that individuals are born with various thresholds of pain perception that may influence results associated with using pain intensity scales (Melzack, R, Wall, PD, 1996). Data Analysis: SAS system for Windows software, release 9.3, was used to analyze the participant data (n=222). Descriptive statistics were used to describe the participants' demographic and environmental characteristics. Additionally, we summarized and reported the responders' answers to the pain location questions in terms of frequency and proportions. We also identified the top three locations on the body for self-reported pain. A value of $P < 0.05$ was used as the indicator of statistical significance.

Results

As shown in Table 1, 55% of respondents were female, 68% of study respondents live off campus.

Table 1: Socio-demographics

VARIABLE		N	%
Gender	Female	121	54.50
	Male	101	45.50
Residence Type	Off-Campus	152	68.47
	On-Campus	70	31.53
	Total	**(N) 222**	**100.0**

Table 4: Results of Field Traffic Stop Scenario

Table 2 describes respondent characteristics. From the 220 effective respondents in Table 2, 90% of respondents carry a book bag four days or more per week; 70% of respondents were undergraduate students, 60% of respondents wore the standard double adjustable book bag, and most of the students were full-time students. The average weight of the book bag students carried was 11.25 pounds with a standard deviation of 4.37. (note that 2 outliers have been removed)

Table 3 shows that 38% of females and 23% of male respondents self-reported pain. As shown in Table 3, a chi-square test was used to determine whether there was a significant difference between self-reported pain by respondent gender. The difference between these variables is significant, $X\ 2\ (1, N = 222) = 8.2019$, $p = 0.0042$.

Table 2: Respondent Characteristics

VARIABLE		N	%
Year of School	Grad Student	72	32.43
	Senior	40	18.02
	Junior	48	21.62
	Sophomore	43	19.37
	Freshman	19	8.56
Enrollment Status	Full-Time	218	98.20
	Part-Time	4	1.80
Days weight is carried	1 day	2	0.9
	2 days	9	4.05
	3 days	11	4.95
	4 days	59	26.58
	5 days ≥	141	63.52
Type of Book Bag	Standard Backpack	137	61.71
	Shoulder Bag	48	21.62
	Messenger Bag	34	15.32
	Other (one strap bag)	3	1.35
	Total	**222**	**100.0**
Bag Weight	**N**	**Mean**	**Std Dev**
	220	11.25 lbs	4.37 lbs

Table 2. Respondent characteristics

Table 3: Self-reported pain by gender

		GENDER				
		Female		Male		X^2
		N	%	N	%	
Pain	No	36	16.22	49	22.07	8.2019*
	Yes	85	38.29	52	23.42	

* p = 0.0042

Table 3. Self-reported pain by gender

According to the data in Table 4, 46% of respondents reported pain in the shoulders, and 37% of respondents reported pain in the lower back. These locations have been examined in order to identify if the bag style associated with reporting pain is in one of these locations.

A Fisher's exact test was used to identify the differences between pain locations among students who reported one pain location by two types of bags—one strap and two strap book bags (standard book bag). The results in Table 6 indicate the difference between the pain locations is significant by the bag types, and the p-value for the Fisher's exact test is p= 0.0013.

Table 4: Location of pain on body

PAIN		PAIN LOCATION				
		Lower Back	Neck	Shoulders	Upper Back	Total
One pain location	N	26	5	33	7	71
	%	36.62	7.04	46.48	9.86	100

Table 4. Location of pain on body

Table 5: Location of pain on body and type of book bag

	TYPE OF BACKPACK			
	Two strap book bag		One strap book bag	
One pain location	N	%	N	%
Lower Back	20	28.17	6	8.45
Neck or Shoulders	14	19.72	24	33.8
Upper Back	6	8.45	1	1.41

Table 5. Location of reported pain on body and type of book bag

A t-test was used to identify if there was a significant difference between the means of book bag weight (lbs.) for students who reported having pain and those not having pain. The results in Table 6 indicate that there is a significant difference between the mean of book bag weight for students who reported having pain and not having pain ($t(220) = -2.52$, $p = 0.0125$). The mean of book bag weight for students who reported having pain ($M = 12.24$, $SD = 5.92$) is significantly higher than students who report not having pain ($M = 10.42$, $SD = 3.86$).

Table 6: The mean of book bag weight lbs. and self-reported pain

	TABLE 8: VARIABLE: WEIGHT OF BAG			
	N	Mean	Std Dev	Std Err
Pain (No)	85	10.42 lb	3.86 lb	0.42
Pain (Yes)	13	11.78 lb	4.60 lb	0.51
Diff (1-2)	5	-1.36	4.33	0.60

Table 6. The mean of book bag weight lbs. and self-reported pain

Table 7 shows no significant difference between one location and multiple locations by bag types among students who reported having pain, X2 (1, N = 79) = 0.1062, p = 0.7445.

Table 7: Book bag weight cut off the mean and self-reported pain by book bag type (weight of backpack ≥ 11.25lbs by the type of backpack

	TYPE OF BACKPACK				
	Standard backpack two strap		One strap bag		X^2
Weight	N	%	N	%	
Weight < 11.25	65	29.55	54	24.55	5.687*
Weight ≥ 11.25	71	32.27	30	13.64	
Pain					
No	58	26.13	27	12.16	2.48**
Yes	137	61.71	85	38.29	

* p = 0.0171, **p = 0.1152

Table 7. Book bag weight cut off the mean and self-reported pain by book Bag type

The relationship is tested by chi-square tests to indicate if there is a statically significant relationship in book bag weight by type of bag and self-reported pain by type of book bag.

The frequencies in bag weight shows significant difference, X2 (1, N = 220) = 5.687, p = 0.0171. However, there was no significant difference in self-reported pain by the type of book bag, X2 (1, N = 222) = 2.48, p = 0.1152.

Table 8 shows no significant difference between one location and multiple locations by bag types among students who reported having pain, X2 (1, N = 79) = 0.1062, p = 0.7445.

Table 8: Self-reported pain and type of backpack

	TYPE OF BACKPACK				
	Double strap backpack		Single strap backpack		X^2
Pain	N	%	N	%	
One location	40	29.2	31	22.63	0.1062*
Multiple locations	39	28.47	27	19.71	

* p = 0.7445

Table 8. Self-reported pain and type of backpack

As indicated in Table 9, the data indicates a statistically significant difference (p= < 0.05) in reporting pain between residence types among students who answered "yes" in pain question, X 2 (1, N = 137) = 6.2966, p= 0.0121.

Table 9: Residence type by self-reported pain among who reported (yes) in pain question

	PAIN=YES				
	One location		Multiple location		X^2
Residence	N	%	N	%	
Off-campus	56	40.88	39	28.47	6.2966*
On-campus	15	10.95	27	19.71	

* p = 0.0121

Table 9. Residence type by self-reported pain among who reported (yes) in pain question

Discussion

From the 220 effective respondents, 90% of respondents carry a book bag four days or more per week—70% of respondents were undergraduate students, 60% of respondents wore the standard double strap adjustable book bag, and most of the students were full-time students. The average weight of the book bag students carry is 11.25 lbs., with standard deviation 4.37. Thirty eight percent of females and 23% of male respondents self-reported pain associated with book bag use. A chi-square test was used to determine whether there is a significant difference between self-reported pain by respondent gender. The difference between these variables was significant, X 2 (1, N = 222) = 8.2019, p= 0.0042. Forty six percent of respondents reported pain in the shoulders, and 37% of respondents reported pain in the lower back. These locations have been examined in order to identify if the bag style associated with reporting pain correlates to one of these locations. A Fisher's exact test was used to identify the differences between pain locations among students who reported

one pain location by two types of bags—one strap and a two straps back (standard book bag). The results indicated a significant difference between the pain location (lower back), bag types (standard double strap), and the p-value for the Fisher's exact test was p= 0.0013.

A t-test was used to identify if there is a statistically significant difference between the means of book bag weight for students who reported having pain and not having pain. The results in Table 7 indicate that there is a significant difference between the mean of book bag weight for students who reported having pain and not having pain (t (220)= -2.52, p = 0.0125). The mean of book bag weight for students who reported having pain (M= 12.24, SD= 5.92) is significantly higher than students who reported not having pain (M=10.42, SD= 3.86).

The relationship was tested by chi-square tests to indicate if there is a statically significant relationship between book bag weight by type of book bag and self-reported pain by type of book bag. The frequencies in bag weight shows significant difference, X2 (1, N = 220) = 5.687, p = 0.0171. However, there was no significant difference in self-reported pain by the type of book bag, X2 (1, N = 222) = 2.48, p = 0.1152. A chi-square was used to identify if students' residence types correlates with self-reported pain. The categories are no pain, one pain location, and multiple pain locations for reporting pain, and the residence types are off-campus and on-campus. The results show a significant relationship between the variables, X 2 (2, N = 222) = 6.3269, p= 0.0423. As indicated in Table 8, the data indicates a statistical difference (p= < 0.05) in reporting pain between residence types among students who answered "yes" in pain question, X 2 (1, N = 137) = 6.2966, p= 0.0121

Conclusion

The purpose of this small-scale pilot study was twofold. First, identify risk factors (book bag style, gender, weight of book bag) associated with self-reported pain due to book bag carriage in a college setting and discuss strategies for prevention. Secondly, obtain preliminary data to determine feasibility of future large-scale studies. There are several significant findings associated with the study. These results suggest that risk factors such as gender, residence location (on- or off-campus), weight, and style of book bag may play a role in self-reported back pain among college students. More study is required to evaluate the frequency, magnitude, and duration of book bag carriage, and the compressive forces exerted on the body, specifically the spine. As mentioned in the study's methods section, there were several limitations associated with the pilot study. Since this research was a pilot study, the researcher used the Center for Disease Control and Prevention's definition of pain as a question in the survey instrument to examine self-reported pain. The study did not use a traditional pain intensity scale. As a result, it is difficult to make any statement about causality. However, according to other researchers, pain can be especially difficult to accurately measure as individuals have differences in thresholds of pain and the perception of pain can vary, even when using pain intensity scales. Based on the findings of this study, educators, health care professionals, and students should consider ways in which to reduce book bag weight carriage. In closing, this researcher contends that it is important to value the self-reporting of pain as early as possible to reduce any potential problems and refer them to medical attention as soon as possible. Self-perceived pain, regardless of the measurement system, may be a symptom of a serious medical condition.

Backpack Study Questionnaire

INSTRUCTIONS:

This study has been approved by IRB #07-12044 and participation in this study is voluntary. Review each question or statement carefully. Respond by circling the most appropriate response. Our research assistant will weigh the contents of each type of book bag carried by each respondent and record it on the form. For additional questions regarding the study contact Kevin Slates, Clinical Assistant Professor at **kslates@indiana.edu**

1. EDUCATIONAL LEVEL:

A. Frosh. B. Soph. C. Junior D. Senior E. Grad.

2. GENDER:

A. Male B. Female C. Other

3. STATUS:

A. Full-time student B. Part-time student

4. HOUSING:

A. On-Campus B. Off-Campus

5. HOW MANY DAYS A WEEK DO YOU CARRY THE BAG?

1 2 3 4 5 > 6

6. HAVE YOU EVER EXPERIENCED PAIN WHILE WEARING YOUR BACKPACK?

Pain: An unpleasant sensation that can range from mild, localized discomfort to agony (source: CDC)

A. Yes

B. No

7. IF YES, WHERE?

A. Upper Back B. Neck C. Shoulders D. Lower Back E. NA

8. INDICATE TYPE OF BAG:

A. Messenger (1 strap)

B. Shoulder (bag/ purse)

C. Standard (2 straps)

D. Other

9. THE RESEARCHER MUST WEIGHT EACH RESPONDENT'S BOOK BAG OR BACKPACK WITH CONTENTS IN IT.

Weight of Bag: _____ Lbs/ounces

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The Workplace Athlete

An alternative approach to musculoskeletal injury prevention and worker health and well-being

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Abstract

For decades, occupational safety and health professionals have sought to mitigate musculoskeletal disorders (MSDs) through traditional ergonomic risk factor analysis and workstation design. Despite these efforts, MSDs; continue to plague nearly all work environments. While there have been innovative solutions developed over the last century that have reduced MSDs, these have primarily resulted from ergonomic workstation redesign, awareness training, and medical case management. This area of injury prevention has shown to be complicated and continues to present implementation difficulties due to natural anthropometric variations of workers' physiological capabilities. This study examines this problem from a different point of view. In addition to designing neutral workstations, addressing and improving individual worker musculoskeletal, mobility, stability, and flexibility, particularly in critical anatomical joints, has significant potential for enabling worker self-conditioning, much as an athlete would undergo physical conditioning to perform physical tasks without injury, even when presented with pre-existing physiological limitations. The objective of this article is to report on data collected and analyzed, then evaluate what, if any, trends can be understood from the FMS assessment measurements when applied in a pre and post-application in combination with a set of mobility-based exercises. This analysis seeks to answer the following research questions: Does the alternative movement improvement program model improve worker physiological condition measured by the Functional Movement Screen? Does the movement improvement model impact musculoskeletal injury prevention efforts? The authors hope to demonstrate movement-improvement programs as a viable complement to traditional Ergonomics and Musculoskeletal Disorder prevention programs.

Introduction

An alternative approach to musculoskeletal injury prevention and worker health and well-being

For decades, occupational safety and health professionals have sought to mitigate musculoskeletal disorders (MSD) through traditional ergonomic risk factor analysis and workstation design. Despite these efforts, MSDs continue to plague nearly all work environments. Since the first publication in 1857 of "An Outline of Ergonomics, or the Science of Work" by Wojciech Jastrzebowski (Jastrzebowski, 1857), scholars, researchers, and practitioners alike have sought to utilize anthropometric, physiological data, medical science, and engineering principles to improve the worker experience, increase productivity, and lessen the potential for injury. While one might assume the problem is centered around work tasks with substantial physical activity or repetitive type work, employees in sedentary workplaces suffer not only injuries, but physical discomfort and health degradation due to the lasting effects of poor body mechanics. According to the Bureau of Labor Statistics, 31% of all workplace injuries in the private sector in 2018 were related to overexertion and bodily reaction resulting in MSDs (BLS, 2018).

Additionally, the United States Bone and Joint Initiative reported in 2016 that an estimated 127 million Americans are affected by musculoskeletal conditions, and these disorders cost an estimated $213 billion in annual treatment, care, and lost wages. Furthermore, there has been much recent public discourse centered on medical research reporting the adverse health effects of a sedentary lifestyle, including metabolic dysfunction, vascular degradation, and bone density reduction. These types of physiological effects can result in diseases such as obesity, diabetes, cancer, heart disease, stroke, and psychosocial disorders (Tremblay, et al., 2010).

While there have been innovative solutions developed over the last century that have reduced MSDs, these have primarily resulted from ergonomic workstation redesign, awareness training, and medical case management. This area of injury prevention has shown to be complicated and continues to present implementation difficulties due to natural anthropometric variations of workers' physiological capabilities. Additionally, some work tasks simply cannot be redesigned to improve ergonomic neutrality due to the transitory or temporary nature of the work. With the recent changes in virtually all work environments due to the COVID-19 pandemic, there will likely be increased instances of working from home and transient workstations rather than permanent desk or office configurations, further exacerbating this problem.

Beyond the office-based setting, work tasks, specifically in construction, maintenance, medical, and emergency response domains, present unique and challenging ergonomic risk factors such as awkward postures, over-exertion, and joint hyperextension or flexion. These tasks are challenging to redesign and modify due to their temporary and sometimes urgent nature with an ever-evolving work activity zone that does not replicate itself on a routine basis—such as the case in more static environments found in manufacturing or assembly line work. For example, welders must often position themselves in cramped or awkward spaces to reach the material's face that must be welded. Utility workers often reach and stretch their extremities to access a point of attachment for pipelines, electrical conduit, or wiring. Many times, workers are restricted in excavations or confined spaces or elevated in aerial lift equipment. Firefighters and emergency medical responders operate in a crisis environment where time is essential to the successful recovery of a victim. They must move quickly, sometimes awkwardly, to either reach a victim or remove them to safety for further assessment and treatment. Medical professionals in trauma centers, intensive care units, and other exigent medical scenarios must move swiftly, sometimes wrestling an unconscious patient to place them in an optimal position for treatment.

Adding to this dilemma are regulatory restrictions placed on workplaces in the United States that prohibit discrimination and utilization of personal medical information to assign workers to job positions based on physical ability. While the Americans with Disabilities Act (ADA) does allow for reasonable accommodation, the reality of accommodating workers with minor movement disorders is problematic, if not impossible, due to the individuality of each person's specific physical condition (Americans with Disabilities Act, 2008). It should be noted that the methods described herein are not intended to be utilized as a pre-employment screen or physical capacity evaluation for placement into an employment position or post-injury medical case management, but rather as a movement assessment to evaluate mobility restrictions and identify areas for individual improvement. Any implementation related to employment or job placement should be done so in consultation with human resources and legal professionals specializing in fair labor practices.

This study examines this problem from a different point of view. In addition to designing neutral workstations that accommodate 96% of the anthropometric population, addressing and improving individual worker musculoskeletal, mobility, stability, and flexibility, particularly in critical anatomical joints, it has significant potential for enabling worker self-conditioning, much as an athlete would undergo physical conditioning to perform physical tasks without injury, even when presented with pre-existing physiological limitations.

The data for this study was collected by a human movement and physiology clinic specializing in novel musculoskeletal injury prevention programs. This particular clinic focuses on best practices in sports medicine and human movement performance and has collected thousands of points of movement data from multiple industrial domains relative to worker joint stability and mobility through a biomechanical assessment called the "Functional Movement ScreenTM" (FMS™). The FMS is an assessment method commonly used in physiological domains such as physical therapy, rehabilitation, sports medicine, and chiropractic practices. The FMS assessment consists of evaluating a series of movements and joint articulation, similar to those used in physical therapy and elite and professional athletic training (Cook, et al., 2006). First developed by Boyle and Coyle as the "joint by joint" concept for the application of physical therapy practices (Boyle & Verstegen, 2012), the FMS functions as an assessment used to measure motor and stabilization skills, grade baseline movement patterns, and determine the existence of movement restriction, mobility asymmetry, or pain with movement. (Bonazza, et al., 2017). The FMS baseline assessment is then combined with mobility-based exercises to improve individual worker joint movements and resilience to injury and then followed up with subsequent assessments to track mobility improvement.

The objective of this article is to report on the data collected and analyzed, then evaluate what, if any trends can be understood from the FMS assessment measurements when applied in a pre- and post-application in combination with a set of mobility-based exercises. This analysis seeks to answer the following research questions: Does the alternative movement improvement program model improve worker physiological condition measured by the FMS? Does the movement improvement model impact musculoskeletal injury prevention efforts?

The Worker is an Athlete

A significant percentage of sports and orthopedic injuries are related to overuse syndromes caused by the repetitive nature of a specific joint movement. These injuries are typically similar to those that occur in industrial workplaces because of their repetitive nature (Sevier, 2000). Since the term "workplace athlete" was first identified in 1985, the argument holds that workers should be assessed and treated for injuries like athletes (Rozmaryn, 1996). This concept is relevant in two critical areas; workers should be physically conditioned for the job/tasks they are expected to perform to potentially prevent injury and improve workplace performance (Amtmann, 2016).

Additionally, workplace athlete programs can enhance or sustain worker health and wellness and quality of life. It has been observed that an athlete's repetitive mechanical movements are precursors to sports-specific injuries due to increased stress on tendons, ligaments, and joints. Similarly, many physical movements performed repetitively on the job site by the worker/laborer often result in the same type of injuries that an athlete will suffer (Viola, 2020).

Research Methods

Working with participating client organizations, pre- and post-assessment data was collected on a variety of types of workers in the following industries: electrical and gas utility, wind turbine operations, food manufacturing, shipyards, mining, construction, oil refining, warehousing, HVAC and plumbing, fire/security alarm installation and maintenance, and customer service call centers. Workers participating in these assessments ranged in age from early twenties to sixty-plus and encompassed a broad spectrum of physical ability from a sedentary lifestyle to physically active. This research project analyzed and aggregated the de-identified data collected from 1,495 participants from 19 different companies across 12 various industries. Informed consent and a waiver for anonymous data release were obtained from each subject before data collection and participation in the program. Authorization was received from participants to review blind assessment scores and aggregate data for research purposes.

Functional Movement Screen

The FMS analyzes unique movement patterns without consideration of weight or repetition. The central goal of the FMS assessment is to detect deficiencies in biomechanics, and clinicians consider the tool to be more reliable than conventional stretching movements. The FMS includes seven specific movement evaluations, which require an appropriate movement of the body's kinetic linking system. The kinetic link model, used to analyze motion, depicts the body as a linked system of interdependent segments. Each of the FMS movements detects movement on distinct parts of the body (Cook, Burton, & Hoogenboom, 2006a).

The movements in the assessment are as follows: (1) deep squat, (2) hurdle step, (3) in-line lunge, (4) shoulder mobility, (5) active straight leg raise, (6) trunk stability push up, and (7) rotary stability (Figure 1). The deep squat and hurdle step movement assesses bilateral, symmetrical, functional mobility of the hips, knees, and ankles. In contrast, the in-line lunge assesses hip and ankle mobility and stability, quadriceps flexibility, and knee stability. The shoulder mobility screen considers a bilateral range of motion, combining internal rotation with adduction and external rotation with abduction. The active straight leg raise tests the ability to isolate the lower extremity from the trunk while maintaining the torso's stability. The trunk stability push-up focuses on stabilizing the spine during upper body movement (Cook, et al., 2006b). FMS allows evaluators to determine baseline primal movement ability to develop improvement plans for individual movement patterns (Bushman, et al., 2016). The screen consists of seven movements that identify vulnerability in joint movements. These primal movement patterns provide an observable presentation of basic locomotor movements. The tests place the participant in extreme bodily positions where weaknesses and imbalances become noticeable if appropriate stability and mobility are not utilized (Cook, et al., 2006a).

Figure 1 – FMS Movements

The seven movements encompass the major joint and muscle groups susceptible to musculoskeletal disorders. The seven individual movement tests are then individually scored on a scale from 0 to 3, with the highest composite score achievable at 21 and the lowest possible score at 0. Clinicians and researchers have established that an FMS score below 14 is considered deficient, and the individual presents a poor function in the targeted area of each movement (Cook, et al., 2006b). A risk assessment model was applied to the total score with 0-11, indicating the highest risk of mobility difficulty, a total score between 11 and 13 indicating a moderate risk of mobility difficulty, and a score higher than 14 indicating the lowest risk of mobility difficulty. It is noted that an FMS score of 2 on any singular movement demonstrates that the movement was executed without the subject reporting pain, although some compensations were detected. Furthermore, a score of 1 indicates that the subject could not perform the movement task within the designated parameters. Subsequently, a score of 14 would mean that a person could complete all seven motions with only minor compensations, no pain, and no asymmetrical movement (Rindal, 2018).

The use of the FMS as a predictor of musculoskeletal injury is controversial. Research studies in professional and elite athletic therapies have yielded contradicting results in terms of the assessment's ability to measure the potential for injury risk accurately. NFL players with FMS scores less than or equal to 14 had an increased chance of injury than players with scores higher than 14 (Kiesel, et al., 2014). Furthermore, studies in athletes performing overhead motions such as tennis or volleyball, which could be assimilated to overhead industrial work performed by electricians, plumbers, and pipe installers, could benefit from a pre-activity assessment tool such as the FMS in combination with training and conditioning programs utilized as mitigative tools in the prevention of shoulder injuries (Cools, et al., 2015). However, later research into the assessment's efficacy did not provide a reliable predictor of sports injury (Philp, 2020).

It is important to note that the FMS should not be utilized as a standalone tool for injury risk prediction; it should be used in combination with a case history of pain and previous injury. Medical case histories, if collected, should be conducted by a licensed healthcare professional. While the FMS has been used for professional and elite athletes, along with military and emergency response personnel, to determine the extent of how susceptible an athlete is to receive an injury, the predominant conclusion was that the FMS alone was most effective at determining a dysfunctional fundamental movement pattern, which could be a precursor to joint degradation or injury, but was inconsistent in predicting the injury itself with any reliability (Philp, 2020). Furthermore, individual components of the FMS may be a better predictor of injury in targeted joint combinations than the overall composite score (Armstrong & Greig, 2018). Previous studies have shown that FMS has high interrater reliability (Cohen's Kappa > 0.85) when assessment technicians are trained and follow the standard procedure for conducting the test (Minick, et al., 2010). In the data collection for this study, FMS assessments were conducted by qualified physical therapists and sports management professionals trained in the FMS assessment procedures.

Two more elements that were considered along with the FMS assessment were pain levels and breathing patterns. Research in military populations suggests that the experience of pain during the FMS had an equal predictive ability with injury risk when the total score was less than 14 points. Soldiers who experienced pain on any of the seven movements were significantly more likely to experience an injury than those who scored the highest point in any individual category (Alemany, et al., 2017). Additionally, breathing mechanics play a crucial role in total body movement. Breathing Pattern Disorders (BPD) have been shown to contribute to pain and motor control deficits, resulting in dysfunctional movement patterns and subsequent injury. Effective breathing patterns are known to contribute to overall movement health. Individuals who exhibit BPD signs are significantly more likely to score poorly on the FMS (Bradley & Esformes, 2014). Further analysis and developments in physiotherapy protocols have informed a multi-faceted approach with an injury prediction algorithm encompassing not only the FMS score but an assessment of any previous injuries, the presence of pain during the evaluation, detection of asymmetry during the evaluation, and analysis based on gender and activity levels (Plisky, 2015).

Results

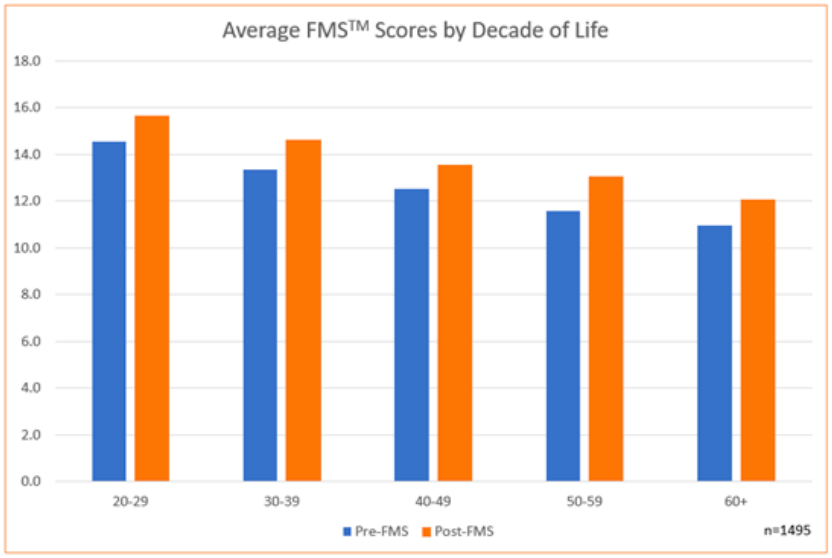

Chart 1 – Average FMS Scores by Decade of Life Analysis

Analysis of pre-and post-assessment scores revealed encouraging results. In the individual FMS test criteria, improvements were noted in the participants' average scores in each movement category (Table 1) after eight weeks of daily self-care routines. Furthermore, when evaluated by participant age, every decade of life category showed improvement in the average score from pre- to post-assessment (Chart 1). The most significant improvement in the individual test score averages occurred in the shoulder mobility test with 22% improvement, while the overall average FMS score improved 16%. Table 2 shows that the average shoulder mobility improvement scores in both the left and right shoulders were 12-14%. The shoulder mobility test measures the distance (cm) between the hands from the distal wrist to the third digit's tip in the opposite hand when the subject reaches behind their back, attempting to touch their opposite fingers together (see Figure 1, item 4). Shoulder mobility is important because studies have shown that a shoulder internal rotation deficit is a predictor of a shoulder injury (Cools, et al., 2015).

Table 1

OVERALL AVERAGE FMS TEST SCORES (N=1495)

Test Name	FMS Baseline	8 week Follow-Up	Score Change	% Change
1. Squat	1.75	1.94	0.19	11%
2. Hurdle Step	1.65	1.91	0.27	16%
3. Inline Lunge	1.70	2.02	0.32	19%
4. Shoulder Mobility	1.48	1.81	0.33	22%
5. ASLR	1.96	2.23	0.28	14%
6. TSPU	2.08	2.40	0.32	16%
7. Rotary Stability	1.34	1.55	0.21	16%
Total FMS Score	**11.95**	**13.86**	**1.91**	**16%**

Table 1 – Overall Average FMS Test Scores

Table 2

SHOULDER MOBILITY				
Average Distance	Pre (cm)	Post (cm)	Delta (cm)	% Improvement
Right	24.82	21.31	-3.51	**-14%**
Left	28.14	24.81	-3.32	**-12%**

Table 2 – Shoulder Mobility

Concerning pain indicators during pre- and post-testing, both Table 3 and Table 4 show that those participants who reported pain during the pretest, on average, showed less reporting of pain during the post-test after the eight-week self-care program. The number of people reporting pain and the number of pain instances during the test showed a 45-47% improvement from the pre-test to the post-test. Given Alemany's results that previous injury and pain experience during FMS are valid predictors of future injury (Alemany, et al., 2017), this finding provides significant evidence supporting the possibility of using this program as a valuable tool for the prevention of injury and improvement of worker comfort and well-being.

Table 3

PARTICIPANTS REPORTING PAIN DURING FMS TEST (N=429)			
Test Name	# Painful Initial	# Painful Follow-Up	Change
Impingement Left	91	52	-39
Impingement Right	119	55	-64
Trunk Extension	105	62	-43
Trunk Flexion	55	26	-29
Squat	44	21	-23
Hurdle Step Left	19	8	-11
Hurdle Step Right	20	5	-15
Inline Lunge Left	37	20	-17
Inline Lunge Right	33	20	-13
Shoulder Left	2	0	-2
Shoulder Right	2	0	-2
ASLR Left	11	8	-3
ASLR Right	12	9	-3
TSPU	71	47	-24
Rotary Stability Left	39	22	-17
Rotary Stability Right	42	19	-23

Pain	INT	FU	% Improved
People w/Pain	356	197	45%
Pain	**INT**	**FU**	**% Improved**
Instances of Pain	702	374	47%

Became Pain-Free
232

Table 3 – Participants reporting Pain During FMS test

Table 4

PARTICIPANTS REPORTING GENERALIZED PHYSICAL PAIN (N=87)		
Age	**Initial**	**Follow-up**
20-29	7	5
30-39	24	12
40-49	26	16
50-59	26	16
60+	4	2
Total	**87**	**51**

Table 4 – Participants Reporting Generalized Physical Pain

Finally, Table 5 reflects the difference in assigned risk between the initial testing to the follow-up. A 28% increase in individuals scoring above 14 was considered low to moderate risk and a 13% decrease in those scoring between 11-13, or moderate risk. Finally, those individuals identified as high risk with less than a score of 11 decreased 16% by increasing their overall mobility and moving into a lower risk category.

Table 5

RISK ASSESSMENT AND CHANGE IN RISK SCORES (N=1494)						
Classification	**Initial**	**% Initial**	**Follow-Up**	**% Follow-Up**	**Delta**	**% Delta**
Green (14+)	457	31%	882	59%	425	28%
Yellow (11-13)	597	40%	408	27%	-189	-13%
Red (<11)	441	29%	204	14%	-237	-16%

Table 5 – Risk Assessment and Change in Risk Scores

Discussion

Analysis of this collected data provides encouraging results concerning the ability to use FMS with an extended movement-improvement conditioning program combined with breathing improvement and pain awareness education. A case study conducted over three years with a single employer in the electric and gas utility company revealed favorable outcomes. This organization reported a 95% savings reduction of direct costs of sprains and strain injuries during the evaluation period. Additionally, this company reported an 81% increase in employee participants classifying as low risk (FMS score >14) for injury after participating in the program. Furthermore, the employer reported that 87% of employees who participated in the program had fewer days missed from work as compared to those workers who did not participate in the program, and 98% of the employee participants would recommend the program to a peer and was generally favorable in their assessment that this program is one part of a more extensive, robust safety and health management system (Rindal, 2018).

Much of the previous clinical research has focused on athletes and military members and anthropometric populations typified by healthy, physically fit, predominantly male, and between the ages of 17–30 years. This point is problematic when considering that the American workforce represents a much broader demographic. However, the data collected here were performed on a broad spectrum of industrial and office-based workers and clearly showed that improvement in mobility and pain awareness could be achieved by participating in self-care movement improvement routines in all age groups. Another anecdotal outcome reported by the FMS test administrators was that participants became more aware of their movement, flexibility limitations, and capabilities through their pre-test scores, even in seemingly "healthy and fit" participants (Cornell, 2020). Those participants became motivated to improve and participate even further.

Implementation of the Workplace Athlete Movement-Improvement Program

Figure 2 Example of Selected Daily Self-Care Exercises

The Workplace Athlete Movement Improvement program is a long-term, sustainable program designed to encourage employees to improve their overall mobility and stability condition. Using adapted tools from physical therapy, chiropractic care, and sports medicine, the movement improvement program described herein combines assessment with regular movement, joint stability, and flexibility exercises. The program begins with an orientation session for employees and organizational leaders to help them understand the fundamentals of movement, flexibility, breathing, and the connection with the potential for MSD injuries. Participating employees are administered a baseline FMS assessment to determine their baseline score (0 to 21) and given instruction and essential tools to perform "Daily Body Care" movement exercises, including a 5 to 10-minute routine focusing on breathing, self-soft-tissue mobilization with a massage roller, and small movement mobility exercises (Figure 2). After the initial eight weeks, a second FMS assessment is administered to the participating employees to assess mobility improvements. During the first eight weeks, employees are encouraged to participate with recommended "Daily Body Care" mobility routine and are given additional specific recommendations based on individual mobility restrictions discovered in the FMS. Additional resources such as web-enabled applications, motivational and educational videos, corporate incentives, competitions, and success story sharing (Figure 3) sustain employee motivation over the length of the program. After the initial eight-week period, employees are encouraged to continue engaging in self-care exercises, share their successes and challenges, and encourage even more employees in the organization to participate. The long-term success of any specialized workplace injury prevention program requires total commitment and support from leadership in terms of time and resources to allow employees to participate in the pre- and post-assessment screening, the daily self-care exercises, and experience sharing across the organization.

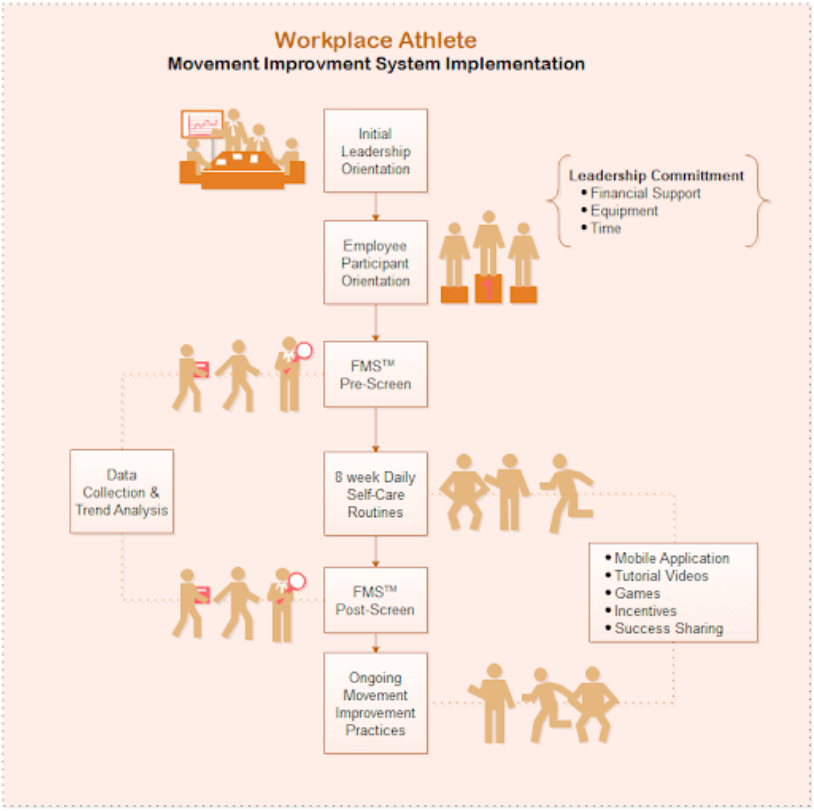

Figure 3 – Workplace Athlete Movement Improvement System – Implementation Process

Application of Movement Improvement programs in a post-COVID-19 World

Since the declaration of the COVID-19 pandemic and subsequent crisis response implemented in healthcare institutions across the globe, a concern has arisen about the physical well-being of the myriad of doctors, nurses, and other health care professionals tasked to work long hours in sometimes grueling conditions to care for the thousands of patients suffering from the coronavirus disease. A recent multinational study of healthcare workers found that approximately 50% of healthcare workers screened tested positive for moderate to very severe psychological distress after extended hours/ days treating patients. There was a strong association between physical symptoms and psychological distress (Chew, et al., 2020). There may be opportunities in the health care field to utilize a program similar to the movement and breathing improvement programs described herein as preventive mechanisms to help medical professionals exercise self-care actions to cope with the severe working conditions they face during this pandemic crisis.

Conclusion

Ergonomic risk factors and musculoskeletal disorders such as sprains and strains continue to plague workplaces, regardless of industry type. The adverse effects of poor body movement and sedentary lifestyles only exacerbate the problem. This data analysis examined whether the alternative movement improvement program model could improve worker physiological ability as measured by the FMS. Would a movement improvement model impact musculoskeletal injury prevention efforts? While the results demonstrate that participation in a program does yield improvement in overall mobility and reduction in reported pain, anecdotal and case study evidence suggests a connection between movement improvement and prevention of injury. In the meantime, safety and health practitioners could utilize this or a similar program as another tool in their toolbox for risk assessment and mitigation. Movement-improvement concepts as a means toward worker health and well-being have broad applications in many workplace domains. Any workplace where people are required to sit, stand, and move could benefit from applying a program similar to what has been described herein.

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