

## RESEARCH ARTICLE

# Accelerometers: Assessing their potential for measuring personal flotation device use on commercial fishing vessels

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**Background:** Falls overboard are the most common cause of fatalities in commercial fishing. As a result, interventions aimed at increasing and measuring the use of personal flotation devices (PFDs) are a high priority. The focus of this study was to explore the use of accelerometers as a means for objectively measuring PFD use on lobster fishing vessels.

**Methods:** For participating vessels, researchers attached an accelerometer to a PFD worn by a crewmember and another to the vessel's wheelhouse. GoPro videos were also employed to record crewmember activities so these could be synchronized with accelerometer outputs. Accelerometer outputs included two distinct measures, the proportional integration mode (PIM) and zero crossing mode (ZCM). Data were fitted to various equations to identify the best method for predicting PFD use.

**Results:** Seven lobster fishing vessels participated in the trial. Data indicated that accelerometers could predict PFD use with a fairly high degree of accuracy. In particular, a logistic equation incorporating PIM values from the PFD and the absolute value of the difference between the PFD PIM readings and the PIM readings from the stationary accelerometer demonstrated the highest degree of accuracy, with correct classifications for 73.3% to 77.6% of the 10-second data intervals. Accuracy was highest when crew members were moving versus stationary. The predictive value of ZCM was comparatively limited.

**Conclusions:** PIM accelerometer readings can be used to measure PFD use with a considerably high degree of accuracy, especially for sternmen who are moving regularly and have the highest risk for falling overboard.

**KEYWORDS**

accelerometers, commercial fishing, lifejackets, objective measures, PFD, safety behaviors, safety technology adoption

## 1 | INTRODUCTION

In 2018, a comprehensive assessment of commercial fishing, work-related mortality data indicated commercial fisheries workers die at significantly higher rates (21-147 deaths per 100 000 full time equivalents [FTEs]),<sup>1</sup> than most US workers (the 2016 average being 3.6 per 100 000 FTEs).<sup>2</sup> In this 15-year assessment of fatal injury

events, researchers found vessel disasters and falls overboard to be the leading contributors of work-related death in the commercial fishing industry. Commercial fishing fatality rates in other countries are reported to be equally high, with rates of 143 deaths per 100 000 person years reported in Australia,<sup>3</sup> while Denmark reports fatality rates that are 25 to 30 times higher than Danish land-based workers.<sup>4</sup> Worldwide, the FAO (Food and Agriculture Organization

of the United Nations) reports that approximately 24 000 commercial fishing fatalities occur annually. Occupational morbidity is equally high and includes health conditions such as decompression illness; musculo-skeletal injuries from chronic, hazardous, ergonomic exposures; infections relating to cuts and baiting; as well as sun exposure.<sup>5</sup>

Although commercial fishermen routinely work in hazardous conditions, with exposures to heavy machinery,<sup>3,6,7</sup> extreme weather,<sup>3,8</sup> long work days/sleep deprivation<sup>6,9</sup> and work-related stress, over the past decade considerable effort has been dedicated to developing safer work conditions and life-saving technologies. A few notable advancements include hands-on fishing safety training courses,<sup>10</sup> hatch and lazarette monitoring systems to reduce vessel flooding,<sup>11</sup> winch entanglement hazard-control technology<sup>12</sup> and personal flotation devices (PFDs).<sup>13</sup>

## 1.1 | Adoption of safety technology and measures are limited

However, adoption of these technologies and practices appears to be low given the consistently high fatal and nonfatal morbidity and mortality rates in the commercial fishing industry.<sup>14,15</sup> In a 2011 assessment of regulatory compliance on commercial fishing vessels in Maine, conducted via at-sea boardings, assessors found that nearly half of the vessels were not compliant with relevant safety regulations.<sup>16</sup> In another qualitative assessment of lobster fishermen use and attitudes toward PFDs, researchers found a number of barriers to their use.<sup>15</sup> Measuring the adoption of safety technology is equally problematic, with the investigator typically forced to resort to subject self-report or other less-than-accurate forms of behavior change assessment.

Studies attempting to measure the accuracy of self-reported data on the use of safety devices have found that this method is often inaccurate. In the case of the use of power-take off (PTO) shields on PTO drivelines, which prevent workers from becoming entangled, the self-reported use of driveline shields was nearly double that which was identified in on-farm equipment audits.<sup>17</sup> In another research project conducted with migrant farmworkers in the NY Hudson Valley farming region, researchers found that there was a strong tendency for farmworkers to report favorable evaluations of safety innovations, despite evidence of not adopting the innovation.<sup>18</sup> Other studies have identified varying rates of accuracy in self-reported PPE use relating to the worker environment.<sup>19-21</sup>

Additional issues with self-reported use of safety technologies involve recall bias, survey fatigue and low response rates, which have become an increasing point of concern in the evaluation of occupational health and safety studies. One study examining the accuracy of reported work-related injuries demonstrates that the integrity of self-reported injury data decreases when recall is greater than 2 months.<sup>22</sup> Other studies have identified similar issues with time-dependent recall.<sup>23,24</sup> Survey fatigue, identified as a lack of interest in survey participation has led to a general decline in response rates to survey-based data collection efforts in public health research.<sup>25</sup>

Although some researchers have attempted to address the shortcomings of self-report with direct observation of safety technology use, this method comes with its own challenges. One such study, conducted to evaluate the impact of regulations on mandatory use of PFDs for small recreational craft in Australia, relied on observations of boaters.<sup>26</sup> However, observational studies, like this one, can be time-consuming, costly and limited to close range observations.<sup>27,28</sup> The Hawthorne effect, a phenomenon where individuals change their behavior because they are being observed, can also impact the validity of observational evaluations.<sup>29</sup>

Given the inherent challenges that come with self-reported data and observational studies of safety behavior, there is a considerable need for objective and unobtrusive methods for monitoring the use of safety technology and worker safety practices. Unfortunately, there has been little progress on this issue as reported in the public health literature.<sup>30</sup> In occupational health and safety studies in particular, assessments have been confined to the development of electronic vapor detection systems and RFID technology to monitor hand hygiene in healthcare workers.<sup>31,32</sup>

Although accelerometers have not previously been used to monitor worker safety behaviors, they have been used increasingly in the public health and safety sector as a means of objectively recording physical activity.<sup>33-38</sup> One accelerometer study attempted to measure vessel stability as a means of reducing vessel sinkings.<sup>37</sup> Accelerometers have also been used to examine the accuracy of physical activity self-reporting<sup>36</sup> and have allowed researchers to measure a number of factors including activity, frequency, duration and patterns of physical activity.

This study seeks to assess the potential for accelerometers to be used as a means of recording safety technology use, or more specifically the use of PFDs on commercial fishing vessels. Researchers hypothesized that the difference in readings between a stationary accelerometer, vs an accelerometer attached to a PFD, could accurately predict whether a PFD is being worn.

## 2 | MATERIALS AND METHODS

### 2.1 | The accelerometer device

Researchers chose the Motionlogger Microwatch accelerometer for use in the trial. The device is manufactured by Ambulatory Monitoring Incorporated of Ardsley, NY and is used in conjunction with Watchware Software (version 1.99.5.1). Motionloggers are roughly the size of a watch and are designed to monitor activity levels, such as in sleep studies. Motion is measured using a triaxial accelerometer, which records two primary endpoints. The first endpoint, zero crossing mode (ZCM), is a count of the number of accelerations above a certain threshold value (typically 0). The second output, proportional integration mode (PIM), is the area under the curve for all accelerations over a given period of time, which in this study was set at 10 seconds.

## 2.2 | Data collection

Accelerometer data were gathered on a sample of lobster fishermen in Massachusetts during the summer of 2018. These subjects were part of a larger study designed to increase PFD use and had indicated their willingness to help with other aspects of the study. Participants were contacted by telephone to arrange a date and time for research staff to accompany them on a work trip to trial the accelerometers. Of the 14 eligible subjects who were contacted, seven were successfully recruited into the study. This study was approved by the Mary Imogene Bassett Hospital Institutional Review Board (project #2038). Written consent was provided by all captains and all crew members of the participating vessels.

The trial involved taking simultaneous readings from one accelerometer (fixed) that was attached to a bulkhead in the wheelhouse vs a second accelerometer that was attached to a PFD. The position of the fixed accelerometer did not change throughout the trip. The accelerometer attached to the PFD was worn by a crewmember, as he or she engaged in their regular fishing activities. PFD accelerometer readings were also taken while the PFD was stowed on the deck and hanging from a hook, so that researchers could obtain readings for it while it was not being worn. At all times, whether the PFD was worn or not, its location and activity were filmed using a small GoPro video camera. Throughout the trial both accelerometers (fixed and PFD) were set to record at 10-second intervals. The GoPro video and the accelerometer readings were synchronized at the beginning of each fishing trip so that researchers could later review the video and classify the activity of the lobsterman at each of these 10 second intervals.

GoPro video footage was coded for corresponding 10-second intervals by two separate coders using Adobe Premiere Pro. These codes classified the crew members' activities into the following categories: (a) "not worn" and (b) "worn". In the "not worn" condition, the codes were classified into these subcategories: (a) stowed high in a fixed position, (b) laying on deck, or (c) stowed above deck swinging from a hook. For the "worn" condition, the activities were divided into the following subcategories: (a) moving, (b) sitting, (c) standing, (d) standing and steering, and (e) sitting and steering. Video codes were then synchronized with accelerometer readings in an Excel spreadsheet and exported into SAS. Table 1 shows the number of data points for each of these conditions for the accelerometer attached to the PFD.

## 2.3 | Data analysis

The data analyses were focused on developing the most accurate algorithm for predicting whether the PFD was being worn or not. This was done for all observations aggregated together and also stratified for each of the crewmember's activities while wearing the PFD (with the exception of the "sitting" activity where there were only 26 observations). The most extensive analyses were conducted for the aggregated data set with a slightly abbreviated method applied to the individual strata. These follow-up analyses were

**TABLE 1** Number and percent of observations in each condition

|                           | % of observations | No. of observations |
|---------------------------|-------------------|---------------------|
| 1. Not worn               |                   |                     |
| (a) Stowed high           | 34.0              | 237                 |
| (b) Laying on deck        | 39.5              | 275                 |
| (c) Hanging from hook     | 26.5              | 185                 |
| 2. Worn                   |                   |                     |
| (a) Moving                | 64.1              | 3090                |
| (b) Sitting               | 0.5               | 26                  |
| (c) Standing              | 11.0              | 530                 |
| (d) Standing and steering | 19.7              | 947                 |
| (e) Sitting and steering  | 4.7               | 226                 |

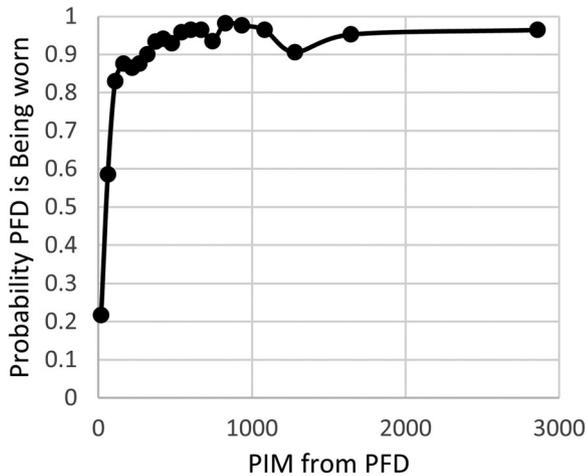
conducted to examine how algorithm accuracy was affected by the various activities of the crew members. The data points of interest for these analyses were the PIM and ZCM readings taken from the stationary and PFD accelerometers.

## 3 | RESULTS

Initially, several plots were created to visualize the relationship between the accelerometer measures and the probability that the PFD was being worn. Plots were created for both the PIM and ZCM readings of the PFD accelerometer, and also for the difference between the PFD and stationary accelerometer readings for these measures (Figures 1,2A and 2B, 3,4A and 4B).

These plots were examined to develop starting points for equations that most closely matched the observed data. In the case of the PFD PIM reading (PIM\_PFD) (Figure 1), it was decided that a general exponential form was reasonable. A plot of the algebraic difference between the two PIM readings, PIM\_PFD and the stationary (PIM\_STAT) (Figure 2A), revealed a nonmonotonic function with a nadir for the probability of the PFD being worn at 0. A second function of the absolute difference between the two values (PIM\_PFD and PIM\_STAT) created a more useful exponential form similar to the function for PIM\_PFD (Figure 2B). The function for ZCM of the PFD was decidedly nonmonotonic (Figure 3). Several attempts were made to fit this function using different level polynomials (quadratic, cubic, etc) without achieving a satisfactory fit. Because of this, the ZCM value of the PFD was not considered further in these analyses, except for a limited exploration that will be explained below. Similarly, neither the algebraic nor absolute difference between the ZCM readings suggested a logical curve fitting approach (Figure 4A and 4B) and were not considered further.

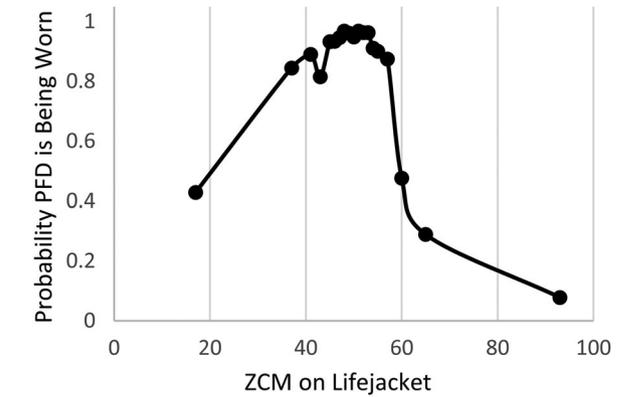
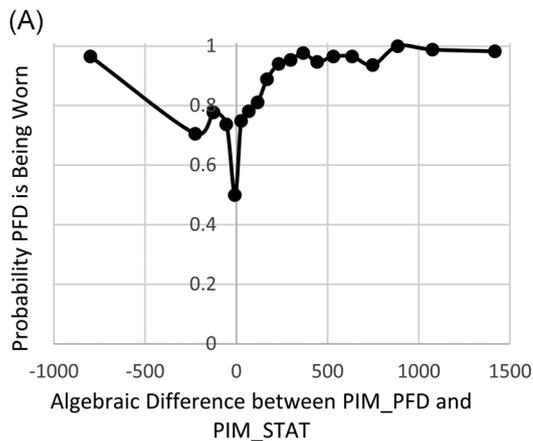
Based on these plots, two general functions that utilized PIM were fitted. The first was a general logistic function that included both the PIM\_PFD and the absolute value of the difference in PIM readings for PIM\_PFD and PIM\_STAT (ABS\_PIM\_DIFF). The second was a general exponential equation that employed only the PIM\_PFD (a suitable exponential equation that employed both PIM and ABS



**FIGURE 1** Probability of wearing PFD as a function of PIM\_PFD. PFD, personal flotation devices; PIM, proportional integration mode

PIM\_DIFF could not be fitted). Figure 5 shows the general form of these two equations using only the PIM\_PFD as an example.

As can be seen, equation 1 (curve with triangle fixed points) is a general logistic form, while equation 2 (curve with square fixed points), is a three coefficient exponential. Before estimating the coefficients for these equations, the data set was divided in half at random into a training data set and a validation data set. Using the training data set, repeated random samples were drawn where the prevalence of the PFD being worn was fixed at either 20%, 50%, or 85%. Curves were then fitted to both PIM\_PFD and ABS\_PIM\_DIFF for a total of 500 iterations at each of the three prevalences. For each iteration, the two general equation forms shown above were fitted to both PIM\_PFD and ABS\_PIM\_DIFF and the coefficients for the logistic form were obtained via maximum likelihood using an iteratively reweighted least squares algorithm. For the general exponential form, the coefficients were obtained iteratively using a Newton-Raphson algorithm. Receiver operator (ROC) curves were created to identify the optimum cutoff probability for the PFD being worn to maximize Youden's J.



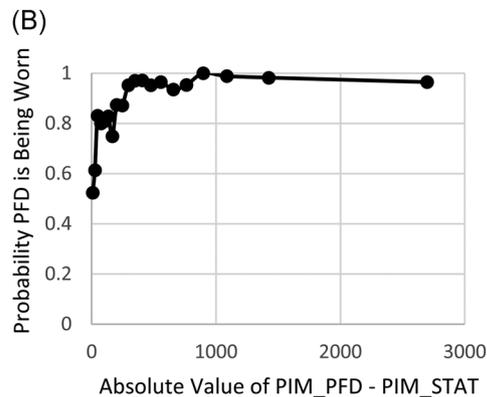
**FIGURE 3** Probability of wearing PFD as a function of ZCM\_PFD. PFD, personal flotation devices; ZCM, zero crossing mode

The value of the regression coefficients was the average taken across the 500 iterations. This resulted in a set of empirically derived coefficients for each level of prevalence, as well as a corresponding cutoff probability for assigning the PFD as being worn ( $y = 1$ ). These regression coefficients and cutoffs are shown in Table 2.

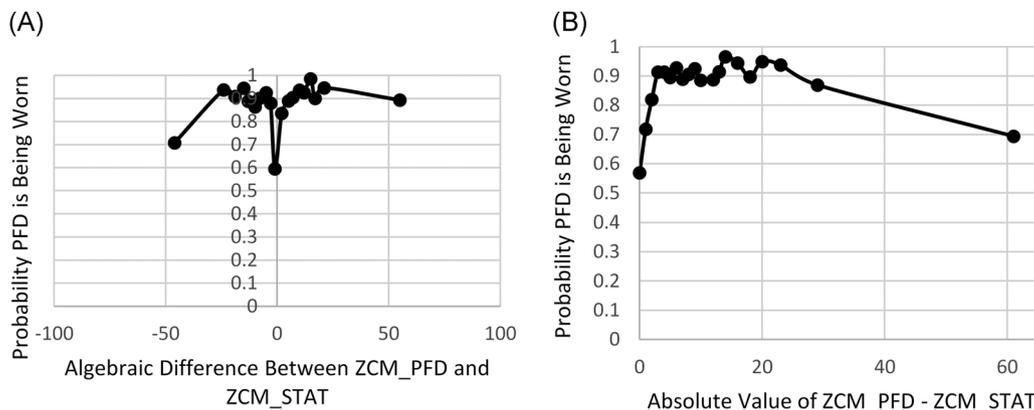
It was found that when the two equations agreed as to  $y = 1$  and  $y = 0$ , the prediction of whether or not the PFD was actually being worn was extremely accurate (Figure 6). Conversely, when the two equations disagreed, the accuracy declined precipitously. Upon further examination of the 10-second intervals for which the two equations using PIM\_PFD disagreed, it was found that they corresponded to intervals where there was a more or less monotonic relationship between ZCM\_PFD and the probability that the PFD was worn.

Therefore, within this range of ZCM values, a logistic function was used to predict the probability that the PFD was being worn for each of the three levels of prevalence. The coefficients for these equations are shown in Table 3.

If the logistic and exponential equations that used PIM\_PFD agreed as to whether or not the PFD was being worn, final assignment was made based on these equations. If the two equations did not agree, final assignment was made based on the logistic



**FIGURE 2** A, Probability of wearing PFD as a function of algebraic difference between PIM\_PFD and PIM\_STAT. B, Probability of wearing PFD as a function of the absolute value of PIM\_DIFF. PFD, personal flotation devices; PIM, proportional integration mode



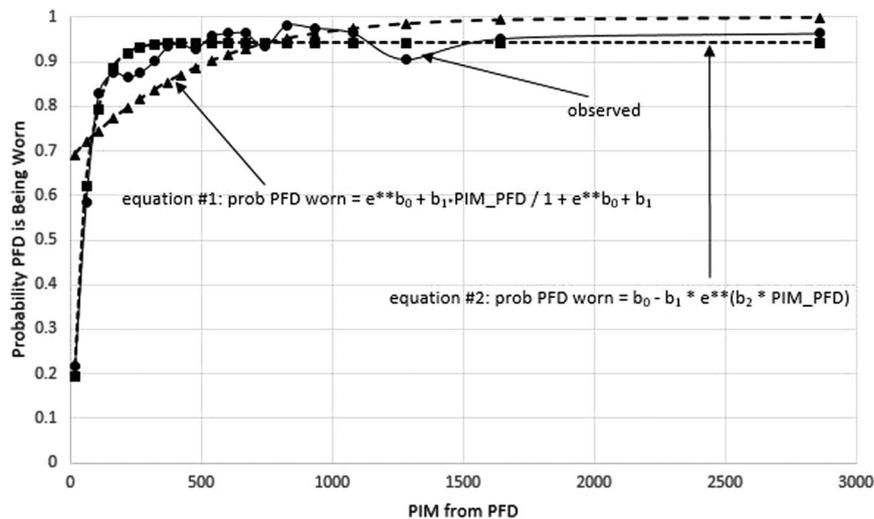
**FIGURE 4** A, Probability of wearing PFD as a function of the algebraic difference between ZCM\_PFD and ZCM\_STAT. B, Probability of wearing PFD as a function of ABS (ZCM\_PFD-ZCM\_STAT). PFD, personal flotation devices; PIM, proportional integration mode

function that employed ZCM\_PFD. Table 4 summarizes the statistical properties of the three equations that were developed from the training data set and also the percentage of correct classifications obtained when the three equations were combined (synthesis of equations) as described above.

As shown in Table 4, the two equations that used PIM\_PFD to assign whether or not the PFD was being worn were in agreement at least 85.2% of the time. Thus, the equation that used ZCM\_PFD to assign whether the PFD was being worn was only operating on at most 14.8% of the data points. It is noteworthy that when the equations using ZCM\_PFD were applied to this subset of the data, their accuracy was higher than either equation using PIM\_PFD on the entire data set. Sensitivity and specificity were relatively consistent across equations and prevalences and tended to be in the mid-70's range. The highest accuracy was obtained using the algorithm described above where final assignment was made according to the two PIM\_PFD equations when they agreed, and on the equation for ZCM\_PFD when they disagreed. The accuracy of this algorithm was 78.3%, 80.0%, and 81.6% for prevalences of 20%, 50%, and 85%, respectively.

Using the validation data set, 515 random samples were then generated for each of the three levels of prevalence (20%, 50%, and 85%). For each of these iterations, the probability that the PFD was being worn ( $y = 1$ ) was estimated using the applicable coefficients and equations from Tables 2 (for PIM) and 3 (for ZCM). For each of these estimated probabilities, the observation was assigned as worn vs not worn using the applicable cutoff probabilities from Tables 2 and 3. These predicted vs observed values for  $y = 1$  were then used to estimate the sensitivity, specificity, and percent correct for the validation (Table 5).

As shown in Table 5, when considering the results from the validation set, the most accurate equation was the logistic that employed PIM\_PFD and ABS PIM\_DIFF. Although the three combined equations (synthesis) produced the greatest accuracy of prediction in the training data set, there was a large drop-off in its predictive accuracy when going from the training to the validation data set. This was likely due to its increased complexity and multiple opportunities to capitalize on chance variability. This was most apparent at 85% prevalence, where the percentage of correct classification fell from 81.6% to only 68.2%. The drop-off in accuracy

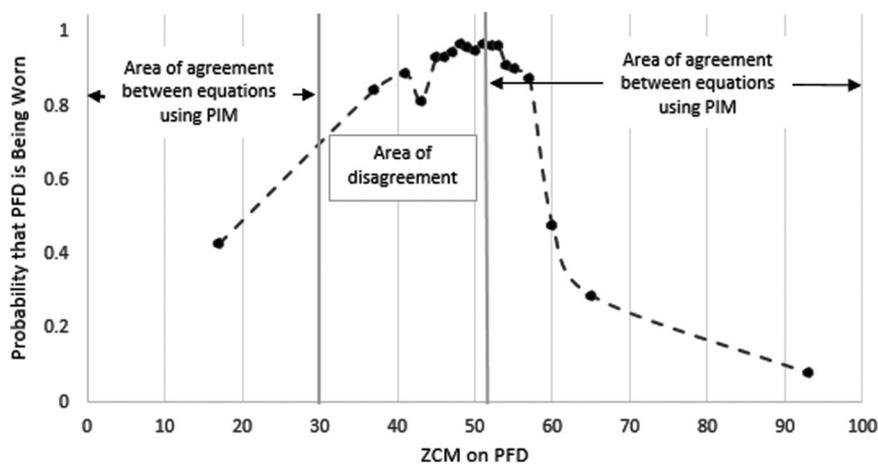


**FIGURE 5** Probability of wearing PFD as a Function of PIM\_PFD. PFD, personal flotation devices; PIM, proportional integration mode

**TABLE 2** Coefficients for equations using PIM\_PFD and ABS\_PIM\_DIFF (logistic) and PIM\_PFD (exponential) obtained from 500 iterations in training data set

|                          | $b_0$ (Intercept) | $b_1$ (PIM_PFD) | $b_2$ (ABS_PIM_DIFF) | Cut-off probability |
|--------------------------|-------------------|-----------------|----------------------|---------------------|
| <i>Logistic model</i>    |                   |                 |                      |                     |
| Prevalence = 20%         | -1.9540           | 0.0004          | 0.0013               | 0.171               |
| Prevalence = 50%         | -0.8740           | 0.0010          | 0.0018               | 0.415               |
| Prevalence = 85%         | 0.4963            | 0.0019          | 0.0020               | 0.763               |
| <i>Exponential model</i> |                   |                 |                      |                     |
| Prevalence = 20%         | 0.3113            | -0.3766         | -0.0170              | 0.309               |
| Prevalence = 50%         | 0.6498            | -0.7640         | -0.0170              | 0.646               |
| Prevalence = 85%         | 0.9316            | -0.8931         | -0.0146              | 0.924               |

Abbreviations: PFD, personal flotation devices; PIM, proportional integration mode.

**FIGURE 6** Graphical depiction of areas of disagreement of PIM equations and the corresponding relationship to ZCM\_PFD. PFD, personal flotation devices; PIM, proportional integration mode; ZCM, zero crossing mode

from training to validation was roughly equivalent for the logistic and exponential equations (~1% to 5%), with the logistic having a slight edge in predictive accuracy in both data sets. In conclusion, the most effective equation for predicting whether or not the PFD was being worn, was the logistic model that employed both PIM\_PFD and ABS\_PIM\_DIFF.

Having identified this final model, researchers explored the effect of the various activities on accelerometer reading accuracy. When the PFD was being worn, the subjects' activities were classified as being (a) moving, (b) sitting and steering, (c) standing, (d) sitting and

steering, and (e) sitting. This assessment was conducted using the same procedure described above for the validation data set, but considering only one activity at a time. Due to the limited number of observations, this analysis could not be conducted for "sitting."

As anticipated, the greatest predictive accuracy of the accelerometer occurred when the subject was moving, with correct classification of 78.0%, 82.9%, and 92.8% for prevalences of 20%, 50%, and 85% respectively. Accuracy for "steering while sitting," while lower than for "moving," was relatively stable across prevalences, ranging between 72.2% and 76.6%. Accuracy for "standing" and "standing while steering" was the lowest, ranging from 31.6% to 62.5% for "standing" and 57.1% and 68.5% for "standing while steering."

**TABLE 3** Coefficients for equations using ZCM\_PFD obtained from 500 iterations in training data set<sup>a</sup>

| Logistic model   | $b_0$ (Intercept) | $b_1$ (ZCM_PFD) | Cut-off probability |
|------------------|-------------------|-----------------|---------------------|
| Prevalence = 20% | 2.518             | -0.072          | 0.230               |
| Prevalence = 50% | 7.218             | -0.134          | 0.506               |
| Prevalence = 85% | 12.697            | -0.207          | 0.846               |

Abbreviations: PFD, personal flotation devices; ZCM, zero crossing mode  
<sup>a</sup>These equations were fit only to data points where the two equations using PIM\_PFD disagreed as to  $\gamma = 1$ .

## 4 | DISCUSSION

As described in the Introduction, identifying reliable and accurate means for measuring worker's use of PPE, in general, and PFD use specifically can be challenging. To date, calculating PPE use has largely been accomplished through self-report or observational

**TABLE 4** Summary of statistical properties of equations developed from training data set

|                                   | Sensitivity | Specificity | % Correct | % Agree logistic with exponential |
|-----------------------------------|-------------|-------------|-----------|-----------------------------------|
| <i>Prevalence 20</i>              |             |             |           |                                   |
| Logistic PIM_PFD and ABS_PIM_DIFF | 76.2        | 76.5        | 76.4      | 85.2                              |
| Exponential PIM_PFD               | 75.0        | 72.4        | 73.0      | 85.2                              |
| Logistic ZCM_PFD                  | 97.6        | 71.0        | 77.0      | N/A                               |
| Synthesis of equations            |             |             | 78.3      | N/A                               |
| <i>Prevalence 50</i>              |             |             |           |                                   |
| Logistic PIM_PFD and ABS_PIM_DIFF | 77.3        | 75.4        | 76.4      | 87.1                              |
| Exponential PIM_PFD               | 74.0        | 73.3        | 74.0      | 87.1                              |
| Logistic ZCM_PFD                  | 96.0        | 75.4        | 87.0      | N/A                               |
| Synthesis of equations            |             |             | 80.0      | N/A                               |
| <i>Prevalence 85</i>              |             |             |           |                                   |
| Logistic PIM_PFD and ABS_PIM_DIFF | 83.0        | 69.0        | 80.9      | 89.1                              |
| Exponential PIM_PFD               | 73.0        | 74.0        | 73.0      | 89.1                              |
| Logistic ZCM_PFD                  | 95.2        | 72.0        | 93.0      | N/A                               |
| Synthesis of equations            |             |             | 81.6      | N/A                               |

Abbreviations: PFD, personal flotation devices; PIM, proportional integration mode; ZCM, zero crossing mode.

studies,<sup>39,40</sup> although both measures introduce biases and can be impacted by respondent or observer fatigue. Identifying more reliable measures of PPE use that do not rely on respondents or observers to remember or repeatedly document PPE use would greatly improve researchers ability to accurately measure the impact of PPE use interventions.

Based on the results from our sea trial of accelerometers, these devices appear to be a fairly effective means for measuring PFD use in situ. In particular, accelerometer readings focused on the size of motion "PIM," were considerably more accurate than readings measuring the frequency of motions "ZCM," while equations that employed the PIM reading and the absolute difference in PIM readings between the fixed and PFD accelerometers were found to be accurate 74.0% to 77.6% in the validation data sets.

It is difficult to assess how our results compare to similar studies, as no previous trials of accelerometers have been conducted to assess PFD use. Accelerometers have been found to be effective in monitoring vessel stability.<sup>37</sup> However, it is unclear whether PIM readings were more accurate than ZCM or how various combinations of accelerometer data improved accuracy in that study, as this was not reported. Other studies attempting to use accelerometers to measure physical activity, similarly lacked comparative data on the accuracy of specific accelerometer readings.

In addition to identifying the most accurate accelerometer readings for predicting PFD use, our research indicates that accelerometer accuracy varies according to crewmember activities. Not surprisingly, readings were almost twice as accurate at measuring PFD use when subjects were moving, as compared to when they were standing still. This limitation in accelerometer accuracy has been noted in other studies that have sought to measure physical activity.<sup>32,34,41</sup> Although our study has determined

that accelerometers are less accurate for measuring PFD use when fishermen are standing still, their utility for measuring PFD use for those at greatest risk on fishing vessels (arguably sternmen who are constantly moving) is still very high. In general, individuals who are mostly engaged in steering, an activity that would be confined to standing vs walking, lifting, and bending, have the least risk as they are typically confined to the wheelhouse, where they have less risk of falling overboard. Sternmen, especially those working in open transom vessels, are at much higher risk for falling overboard due to an entanglement, slip, or trip.

The current study faced a unique challenge in that the subjects were standing on a constantly moving platform, ie, fishing vessel. Even so, the study could predict the use of the PFD with considerable accuracy. In other applications where the subject is not standing on a moving platform, it would be far easier to use an accelerometer to measure whether or not a recommended safety device was being worn, as readings would be zero if the device were removed. Examples of applications of this methodology would include measuring the use of hard hats on a construction site, hearing protection in a noisy factory or respiratory protection on a farm.

All of these applications would be simplified by the fact that a second accelerometer analogous to the one that was fixed to the boat in the current study, would not be necessary. In these cases, the only outcomes needed would be the PIM and ZCM readings from the accelerometer that is attached to the safety device. These applications would also require detailed knowledge of the movement patterns involved for any particular work task. From these, the investigator would need to determine how great of a period of consecutive zero readings would be indicative of nonuse of the safety device. For example, for a construction worker who is typically in constant motion, a relatively brief interruption in movement may be indicative of nonuse. In contrast, for a

**TABLE 5** Comparison of percent correct in training vs validation data sets

|                                   | % Correct training | % Correct validation |
|-----------------------------------|--------------------|----------------------|
| <i>Prevalence 20</i>              |                    |                      |
| Logistic PIM_PFD and ABS PIM_DIFF | 76.4               | 74.0                 |
| Exponential PIM_PFD               | 73.0               | 74.0                 |
| Synthesis of equations            | 78.3               | 73.2                 |
| <i>Prevalence 50</i>              |                    |                      |
| Logistic PIM_PFD and ABS PIM_DIFF | 76.0               | 73.3                 |
| Exponential PIM_PFD               | 74.0               | 71.5                 |
| Synthesis of equations            | 80.0               | 71.4                 |
| <i>Prevalence 85</i>              |                    |                      |
| Logistic PIM_PFD and ABS PIM_DIFF | 80.9               | 77.6                 |
| Exponential PIM_PFD               | 73.0               | 68.0                 |
| Synthesis of equations            | 81.6               | 68.2                 |

relatively stationary employee such as a supervisor, this may not be the case. Therefore, in any application to examine safety device use in other work environments, a pilot study such as the one described here may be necessary to develop the necessary criteria for determining use. However, as long as the application is one where the person is on a stationary surface, we believe that the pilot study could be much less extensive than the one described here.

Although the results from our study indicate that accelerometers can accurately predict PFD use much of the time on commercial fishing vessels, there are some limitations to their widespread use. In particular, high-quality accelerometers can be extremely expensive. On average the cost of the accelerometers used in our study were roughly \$1000 per device. Additionally, traveling to the boat to ensure the proper set-up of fixed and PFD accelerometers can be time-consuming and expensive when labor and travel costs are combined. Lastly, these devices are battery powered, so periodic recharging is necessary to ensure that data continues to be collected over periods longer than 1 month.

#### 4.1 | Study limitations

Given the considerable investment in time and effort to conduct this initial sea trial of accelerometers, as well as the cost of accelerometer rental, it was not possible to recruit a large sample of lobster fishing vessels in the analysis. As such, the generalizability of the data is impacted by both the number of vessels, as well as the variety of vessels included in the analysis. For example, many of the vessels included in the sea-trial were small to mid-size boats with only a few crew members, fishing within a day's journey of the coastline. Although these types of vessels account for the majority of lobster fishermen in MA and ME, there are some vessels that are larger than travel farther (ie, offshore fishermen) than the vessels described in our study. As

such, it is possible that differences between the PFD accelerometer readings and the wheelhouse accelerometer readings would be different and potentially less reliable in predicting PFD use. However, this initial trial has demonstrated that using accelerometers to predict PFD use is a potentially promising method for validating or replacing self-report measures, and the methods described for testing these devices in real-life conditions will pave the way for more extensive assessments of worker PPE use with accelerometers. Finally, although the accelerometer can be used to measure whether or not the PFD is being worn, we do not currently have an algorithm to measure whether or not it is being worn correctly.

## 5 | CONCLUSIONS

The limitations of self-reported data, including reporting information incorrectly, and providing answers that are either socially desirable or perceived to please the investigator, are well known. Given this, the use of accelerometers to objectively measure PFD use, while not perfect, is a viable alternative to self-report. This is particularly encouraging given that the device is designed to measure motion rather than the use of protective technology per se. It is also noteworthy that the technology was effective despite the fact that the work environment itself (the boat) was also in constant motion. These results also indicate that when using accelerometers for this purpose, it is the size of the movements (PIM), rather than their frequency (ZCM), that is most predictive.

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### DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

### AUTHOR CONTRIBUTIONS

All authors participated in the conception or design of the work, as well as the acquisition, analysis, or interpretation of the research

data. MK developed study protocols, organized vessel data collection activities, researched and perfected data collection technology, ensured data accuracy, developed a coding scheme for GoPro data and synchronized GoPro and motionlogger accelerometer data, with assistance from LH. RW and JE assisted with the recruitment of subjects. Lastly, PJ and JS were primarily responsible for drafting the manuscript. All authors were asked to review the final draft, have provided final approval of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

## ETHICS APPROVAL AND INFORMED CONSENT

This study was approved by the Mary Imogene Bassett Hospital Institutional Review Board (project #2038). Written consent was provided by all captains and all crew members of the participating vessels.

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