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Proposed pedestrian pathway roughness thresholds to ensure safety and comfort for wheelchair users

Jonathan Duvall, MS\textsuperscript{a,b}, Eric Sinagra, MS\textsuperscript{a,b}, Rory Cooper, PhD\textsuperscript{a,b}, and Jonathan Pearlman, PhD\textsuperscript{a,b}

\textsuperscript{a}Human Engineering Research Laboratories, Department of Veterans Affairs, Pittsburgh Healthcare System, Pittsburgh, Pennsylvania, USA; \textsuperscript{b}Department of Rehabilitation Sciences and Technology, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, Pennsylvania, USA.

ABSTRACT
In the United States, over three million people use a wheelchair for their primary means of mobility and they rely on functional and accessible pathways to participate in their communities. The Americans with Disabilities Act Accessibility Guidelines related to pathway roughness are currently ambiguous, subjective and therefore unable to be measured. Consequently, many public pathways are sufficiently rough to result in harmful vibrations and discomfort for wheelchair users. In previous research, subjective ratings and root-mean-square accelerations were reported from subjects traveling over surfaces with various roughnesses in their own wheelchairs. The purpose of the current study is to use previous data to propose roughness thresholds by correlating the roughness of surfaces to vibration data and subjective ratings from wheelchair users. The results suggest a pathway roughness index threshold of \( \leq 50 \text{ mm/m} \) (1.2 in./ft) for a surface segment of 100 m (328 ft) in length, and \( \leq 100 \text{ mm/m} \) (1.2 in./ft) for a surface segment of 3 m (9.8 ft) in length would protect wheelchair users against discomfort and possible health risks due to vibration exposure. For surfaces of different lengths, a 3 m (9.8 ft) and 100 m (328 ft) moving window should be used.

Introduction
People with disabilities can have very active lifestyles. A study has shown that power wheelchair users travel an average of 1.6 km on a normal day, and in active and highly accessible environments, power wheelchair users will travel up to about 8 km per day (Cooper et al., 2002). Another study of manual wheelchair users determined that on average days they travel 2.0 km, and in very accessible settings, they will travel an average of 6.5 km per day. In this study, one subject traveled 19.4 km in 1 day (Tolerico et al., 2007).

Some factors that influence activity level and travel distances are the degree to which the wheelchair rider is safe and comfortable, and the amount of effort that they will need to exert to travel over the surface. A typical measure of comfort is to evaluate the levels of whole-body vibrations (WBVs) to which wheelchair users are exposed as they travel over uneven surfaces. Occupational hazards research has linked WBV exposure to pain, discomfort, and injury to several of the body’s vital organs (Seidel & Heide, 1986). Studies show that exposure to high levels of vibration may be correlated to many symptoms, such as muscle fatigue (Zimmermann, Cook, & Goel, 1993), back injury (Pope & Hannson, 1992; Pope, Wilder, & Magnusson, 1999), neck pain (Boninger et al., 2003), and disc degeneration. Research has revealed that the seated position, which is the posture during wheelchair use, is a damaging position for the spine and many associated body tissues during vibrations (Seidel & Heide, 1986). While most of this literature was produced in the context of occupational hazards and seats in motor vehicles, the same can be applied to wheelchair use. However, the damage that these vibrations cause to wheelchair users could be underestimated due to differences in body composition, atrophy, and instability. Daily vibrations experienced during all movements of wheelchair riding can also increase an user’s rate of fatigue (VanSickle, Cooper, Boninger, & DiGiovine, 2001) and limit their community participation. Because of these damaging effects, it is vital to comprehend and attempt to limit the amount of WBVs that are experienced by wheelchair users when they navigate over pathways (Cooper et al., 2004; Requejo, Maneekobkunwong, McNitt-Gray, Adkins, & Waters, 2009).

The International Standards Organization’s (ISO) 2631-1 standard, Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibrations (ISO, 1997), is a widely used standard for vehicle vibration analyses and prescribes thresholds for fatigue, safety, and comfort, called the exposure caution zone. The exposure caution zone is determined based on the weighted magnitude of acceleration and time of exposure and gives the maximum allowable threshold for human comfort and safety. ISO 2631-1 states that, for a 4- to 8-hour period, a root-mean-square (RMS) value of 1.15 m/s\(^2\) is the maximum allowable vibration value. Long-term (e.g., several years) exposure of vibration levels within the caution zone may still result in an increased risk of
health impairment, which can cause people who use wheelchairs to avoid participating in their communities.

The Architectural Barriers Act of 1968 (ABA) mandates that facilities that are designed, built, or altered with the use of federal funding or leased by federal agencies must be accessible to the public. The Americans with Disabilities Act of 1990 (ADA, 1990) greatly expanded the range of application and details of the ABA. The ADA states that “physical or mental disabilities in no way diminish a person’s right to fully participate in all aspects of society” (ADA, 1990, § 12101(a)(1)). Likewise, the ADA states that a purpose is “to provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities and to provide clear, strong, consistent, enforceable standards addressing discrimination against individuals with disabilities.” (ADA, 1990, § 12101(b)(1)). Title V of the ADA mandated the creation of the Architectural and Transportation Barriers Compliance Board (Access Board), and for it to create minimum guidelines “to ensure that buildings, facilities, rail passenger cars, and vehicles are accessible, in terms of architecture and design, transportation, and communication, to individuals with disabilities.” (ADA, 1990, § 12204(b)).

The Access Board has published the ADA Accessibility Guidelines (ADAAG) for Buildings and Facilities, which give specific definitions and measurements about what is considered accessible. However, the only specifications related to floors or other pedestrian surface characteristics are that they “shall be stable, firm, and slip resistant.” (ADAAG, 2010, Appendix D to Part 1191, § 302.1). Unfortunately, these restrictions are subjective, not measurable, and do not directly address the issue of surface roughness. The current ADAAG guidelines do provide specifications for width and slope, but do not provide specifications for pathway roughness, except that obstacles in the path of travel should not be more than 12.7 mm (0.5 in.) high. The frequency of the obstacles, profile, and orientations of safe and passable obstacles are not described (ADAAG, 2010). The absence of guidelines related to roughness is a major limitation of the ADAAG, as there are many people involved in the development and construction of public pathways (community councils, city planners, architects, and contractors), each of which likely do not understand the effects that terrain characteristics have on the health, comfort, and safety of wheelchair users. Currently, the Access Board is updating their rules in an effort to make public rights-of-ways (PROW) more accessible for people with disabilities (U.S. Access Board, 2011). These PROW rules will likely be accepted and promulgated in 2015, and will formalize the rules on many surface characteristics, including width, passing spaces, grade, cross slope, curb ramps, and surface transitions. They are also looking to include requirements on surface smoothness and rollability (U.S. Access Board, 2011).

To measure the extent of WBV exposure to which wheelchair users are exposed during a typical day, a study was conducted to examine the health risks of WBV exposure to wheelchair riders in different environments (Garcia-Mendez, Pearlman, Boninger, & Cooper, 2013). Vibration dataloggers, seat occupancy sensors, and wheel encoders were attached to users’ manual wheelchairs, and vibrations on the wheelchair were measured for 2 weeks at a national wheelchair competition and in their own community. The results confirmed that all of the subjects were exposed to WBV levels at their seat surface that were above or within the health caution zone described by the ISO 2631-1 standard (Garcia-Mendez et al., 2013).

Another study looked at the vibration effects of brick shape and orientation of nine different newly-installed sidewalk surfaces (Wolf, Cooper, Pearlman, Fitzgerald, & Kelleher, 2007). A poured concrete (control) surface was compared to various configurations of brick surfaces. The brick surfaces varied in composition (clay, concrete), shape (bevel size, no bevel), and angle of brick placement (45°, 90°). Accelerations were monitored at the seat and footrest of the wheelchair as subjects traveled over the surfaces. They determined that the surface with no bevels and 90° orientation resulted in the lowest WBV and significantly lower WBV than the control, standard poured concrete surface. The results also indicated that the surface with an 8-mm bevel and 90° orientation had the highest WBV. The reason that the poured concrete control surface, with 4 feet between joints, caused significantly higher vibrations than a brick surface, with 8 inches between joints, was most likely a result of the large gaps between the slabs of concrete compared to the very small ones between bricks (Wolf et al., 2007).

Another research study using six of the same surfaces (poured concrete control; 0, 2, and 8 mm bevels with 90 orientation; and 0 and 4 mm bevels with 45 orientation) determined that power wheelchairs driving at a speed of 1 m/s would exceed the ISO 2631-1 threshold for 8 hours of exposure to WBV using the 8 mm bevel, 90° orientation surface, and the 4 mm bevel, 45° orientation surface. Driving at a speed of 2 m/s, the exposure threshold would be exceeded on all surfaces in less than 3 hours of continuous driving (Cooper et al., 2004). While wheelchair users will not typically drive non-stop for 3 hours, they do travel more than 8 hours a day on average, and are exposed to some amount of vibrations during all movement.

There are many existing standards and techniques for evaluating roadway roughness using both subjective and objective data. Adapting the measurement and analysis techniques to sidewalks and pathways used by wheelchair users are shown in a previous article by Pearlman, Cooper, Duvall, and Livingston (2013).

A previously published study investigated the correlation between the pathway roughness index (PRI)—an analysis technique adapted from the international roughness index (IRI) used on roadways (ASTM International, 2008) of various surfaces—and WBV exposure to wheelchair users (Duvall et al., 2013). PRI is an index that calculates the vertical displacement of a standard wheel as it travels over the horizontal distance of a surface, while the IRI only calculates the vertical deviations of the surface itself over a horizontal distance. Subjects were asked to use their wheelchair to travel over several outdoor community surfaces, as well as a 4.88 m (16 ft) indoor test platform of “designed” surfaces, which had a sequence of wood slats that were altered to vary the roughness from very rough to almost perfectly smooth. Before the subjects travelled over the surfaces, tri-axial accelerometers
were attached at the seat frame, backrest, and footplates to record vibrations. While these vibrations may not have been the exact vibrations felt by the wheelchair user because of the cushions they used, these locations are typically used for vibration studies due to the difficulty of placing sensors above the cushion and below the person. The transmissibility of vibrations of several wheelchair cushions has been investigated (Garcia-Mendez, Pearlman, Cooper, & Boninger, 2012).

After subjects traveled over a surface, they were asked to answer a short questionnaire based on ASTM 1927-98 to evaluate the surfaces (ASTM International, 1998). The questionnaire is shown in Figure 1 and asked the subject to rate the surface from 0–5, and asked if they felt it was acceptable or not. The PRIs of these surfaces were determined by using a custom-built measurement device called the Pathway Measurement Tool (PathMeT) (Sinagra et al., 2013), which was instrumented with an Acuity AR700 (Schmitt Industries, Portland, OR) distance measurement laser oriented perpendicular to the ground, and a wheel encoder. PathMeT was developed to measure the profile of a surface with millimeter resolution by simply pushing the device over the surface. The PRI analysis was then applied to the profiles of the surfaces to calculate the correlation of the vibrations and PRI values of the surfaces. An example of the results of the correlation is shown in Figure 2. The three thresholds depicted in Figure 2 come from ISO Standard 2631-1, and represent the maximum amount of time a person should be subjected to a certain level of vibrations. For example, the long dashed lines show that a person should not be subjected to vibrations with an RMS value of 3.5 m/s² for more than 10 minutes.

The goal of this work was to translate the previous research evidence on WBV exposure and PRI into practical thresholds that stakeholders in the field can use to characterize whether the sidewalk poses a comfort or health risk to wheelchair users. Specifically, we propose a PRI threshold based on the previous subject testing that could be used to determine whether a pathway is safe, moderately safe, or unsafe for wheelchair users. An application of the measurement and analysis approach using an experimental set of real-world surfaces is also provided.

Methods

Roughness threshold

Based on data reported in the previous subject testing study (Duvall et al., 2013), possible PRI thresholds were selected that corresponded to health risks related to WBV exposure and the subjective feedback gathered from the users. Several factors were considered when generating the suggested PRI thresholds, which are described next.

PRI and WBVs

The values selected for the thresholds should fall somewhere in the middle of the PRIs measured, so that harmful WBVs can be limited while not being too restrictive (that is, setting a threshold that requires pedestrian pathways to be perfectly smooth). It was noted that, instead of determining one specific threshold, selecting a range similar to the ISO 2631-1 health guidance zone to describe the roughness indices could be more effective. One proposed threshold would be the lower threshold of the health guidance zone, where all surfaces with a PRI under that threshold would be considered safe and comfortable. Another proposed threshold would be a higher value, where all surfaces with a PRI value above that value will likely cause harmful WBVs and be uncomfortable for the wheelchair user. Surfaces with PRI values between those two thresholds would be considered moderately safe.

PRI and length of segment

It was also noted that it would be useful to develop the variable thresholds based on the length of the surface segment. A surface that is only a few feet long, such as detectable warning surfaces at curb cuts, could be rougher than pathway surfaces that are hundreds of feet or blocks long, because the damage caused by WBV is related to exposure time.

PRI and duration of exposure

Wheelchair users are continuously exposed to WBVs that, over time, may reach harmful levels. There are several possible duration thresholds based on the data collected. If the PRI threshold is based on the RMS values for the vibrations, it could be selected as the lower threshold or the higher
threshold of the ISO Standard 2631-1 health guidance zone, and it could be based on 30 minutes of exposure or any other amount of time.

**PRI and subjective feedback**

The thresholds could also be based on the questionnaire data. Using the questionnaire data, it could be the PRI equivalent of 80% acceptable, 60% acceptable, or any other percentage. It could also be the PRI equivalent of the rating for "good" (3.5), "fair" (2.5), or anywhere else along the rating spectrum.

**Community-based data collection**

To give some examples of surfaces that would be acceptable and unacceptable, PathMeT was used to collect profiles from various different pedestrian pathway surfaces in a major U.S. city, with the results shown below. This version of PathMeT, as opposed to the one used in Duvall et al. (2013), was able to be pushed directly over the surface and did not require running on flat boards to filter out noise caused by the surface. Figure 3 shows a picture of this version of PathMeT.

**Results**

**Roughness threshold**

The results of the previous vibration study showed that some surfaces can cause discomfort and could cause health risks to wheelchair users. Some possible selections for the PRI thresholds are given in Table 1 and Table 2. The lowest value is 16.7 mm/m (0.2 in./ft), which is italicized in Table 1, and is lower than the roughness of every surface that was tested. The highest value is 205.8 mm/m (2.47 in./ft), which is also italicized in Table 1, and is higher than every surface that was measured.

Based on the previous vibration and questionnaire results and the PRI calculation (Duvall et al., 2013), two PRI thresholds were proposed and are shown in Table 3. The maximum PRI threshold proposed for any short surface segment (<3 m) is 100 mm/m. This PRI corresponds closely to the lower threshold of the ISO 2631-1 threshold for WBVs lasting less than 10 minutes, and is close to the PRI of surfaces that are rated "fair" and acceptable by 50% of the wheelchair users tested in the study. Of the 18 community and nine designed surfaces, four of the community surfaces and two of the designed surfaces that were tested would be unsafe if this threshold was selected. Similarly, a PRI threshold of 50 mm/m is proposed as the threshold for any surface segment that is significantly long (≥100 m). A surface with this PRI would be rated as acceptable by more than 75% of the wheelchair users and would not likely cause injury to wheelchair users unless they traveled over that surface for more than two hours. Seven of the community surfaces and five of the designed surfaces that were tested would be safe to be used at high distances if this was the standard. The 3 m length was chosen to allow for detectable warning pads at curb cuts and transitions. The 100 m length was chosen to roughly correspond to the length of a city block. To evaluate surfaces of any length, two moving windows of 3 m and 100 m should be used to test if any 3 m or 100 m segments of that surface are above the proposed thresholds. For example, surface segments longer than 100 m should be analyzed with a 100 m and 3 m moving window to ensure that no 3 m segments are above 100 mm/m, and that no 100 m segments are above 50 mm/m. Surface segments that are less than 100 meters, but greater than 3 meters, should still have a total PRI that is less than 100 mm/m, but could be larger than 50 mm/m. However, no 3 m section of the surface should have a PRI above 100 mm/m.

Using the speed of 1 m/s as an estimate (the speed used for many of these vibrations studies and slightly slower than average walking speed), it can be determined that traveling for 10 minutes over a surface with a PRI of 100 mm/s would equate to reaching the vibration threshold after 0.6 km

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**Table 1. PRI values for duration of exposure based on ISO standard 2631 (mm/m).**

<table>
<thead>
<tr>
<th>Exposure time</th>
<th>Health guidance zone</th>
<th>PRI threshold (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>2 hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10 min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Italics indicate highest and lowest values.

---

**Table 2. PRI threshold options (mm/m) based on questionnaire data.**

<table>
<thead>
<tr>
<th>Surfaces, chairs</th>
<th>% Acceptable</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
<td>75%</td>
<td>50%</td>
</tr>
<tr>
<td>All surfaces, all chairs</td>
<td>62.50 99.17</td>
<td>49.17 95.00</td>
</tr>
<tr>
<td>All surfaces, manual chairs</td>
<td>60.00 96.67</td>
<td>51.67 98.33</td>
</tr>
<tr>
<td>All surfaces, power chairs</td>
<td>65.83 102.50</td>
<td>46.67 93.33</td>
</tr>
<tr>
<td>Designed surfaces, manual chairs</td>
<td>61.67 103.33</td>
<td>52.50 102.50</td>
</tr>
<tr>
<td>Designed surfaces, power chairs</td>
<td>56.67 99.17</td>
<td>38.33 83.33</td>
</tr>
</tbody>
</table>

**Table 3. Proposed PRI thresholds and characteristics related to why they were chosen.**

<table>
<thead>
<tr>
<th>PRI threshold</th>
<th>Surface lengths</th>
<th>ISO Standard 2631 exposure time</th>
<th>Percent of people that rated it acceptable (%)</th>
<th>Number of community surfaces above threshold</th>
<th>Number of designed surfaces above threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm/m</td>
<td>&gt;100 m</td>
<td>&gt;120 min</td>
<td>75</td>
<td>11/18</td>
<td>4/9</td>
</tr>
<tr>
<td>50 mm/m</td>
<td>&lt;3 m</td>
<td>&lt;10 min</td>
<td>75</td>
<td>11/18</td>
<td>4/9</td>
</tr>
<tr>
<td>100 mm/m</td>
<td>&gt;100 m</td>
<td>&gt;120 min</td>
<td>50</td>
<td>4/18</td>
<td>2/9</td>
</tr>
<tr>
<td>100 mm/m</td>
<td>&lt;3 m</td>
<td>&lt;10 min</td>
<td>50</td>
<td>4/18</td>
<td>2/9</td>
</tr>
</tbody>
</table>

---
(0.37 miles). Similarly, traveling for 2 hours over a surface with a PRI of 50 mm/m would equate to reaching the vibration threshold after 7.2 km (4.5 miles).

In order for a surface to be evaluated to see whether it would be acceptable using these thresholds, a profile of the surface would need to be collected and analyzed using two filters. One filter would scan the surface profile data using a moving window of 3 m to see if any 3 m segment had a PRI above 100 mm/m. The other filter would scan the surface profile data with a 100 m moving window to check if any 100 m segments had a PRI that exceeded 50 mm/m.

**Community-based data collection**

Table 4 shows the image and PRI of a few of the surfaces that were measured for more than 100 m. According to the proposed threshold for roughness, PRI should not exceed 50 mm/m for distances of 100 m or greater. Thus, surfaces below the proposed threshold of 50 mm/m are considered to be safe, and are italicized; surfaces with PRI between 50 and 100 mm/m are considered to be moderately safe, and are underlined with a solid line; and surfaces with a PRI exceeding the proposed threshold of 100 mm/m are considered unsafe, and are bold and italicized.

**Discussion**

This research took previous research and roughness measurement methods and provided a useful way to evaluate pedestrian pathways for safety and accessibility. The proposed roughness thresholds have been produced by applying occupational and vehicle standards to wheelchair use and could be

<table>
<thead>
<tr>
<th>Picture</th>
<th>PRI (mm/m)</th>
<th>Picture</th>
<th>PRI (mm/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Vertical brick" /></td>
<td>30.7</td>
<td><img src="image" alt="Square concrete" /></td>
<td>45.5</td>
</tr>
<tr>
<td><img src="image" alt="Horizontal brick" /></td>
<td>55.1</td>
<td><img src="image" alt="Concrete" /></td>
<td>62.2</td>
</tr>
<tr>
<td><img src="image" alt="Horizontal brick" /></td>
<td>64.3</td>
<td><img src="image" alt="Horizontal brick" /></td>
<td>74.1</td>
</tr>
<tr>
<td><img src="image" alt="Asphalt" /></td>
<td>85.1</td>
<td><img src="image" alt="Horizontal brick" /></td>
<td>161</td>
</tr>
<tr>
<td><img src="image" alt="Chip and seal" /></td>
<td>115</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*These two surfaces were measured using an earlier version of PathMeT; Italics indicate surfaces below the proposed threshold of 50 mm/m; Underline indicates surfaces with PRI between 50 and 100 mm/m; Bold and italics indicates surfaces with a 355 PRI exceeding the proposed threshold of 100 mm/m.
used to determine whether pedestrian pathways should be considered safe, moderately safe, or unsafe for wheelchair users. They could be used by the Access Board for the development of the PROW rules related to surface roughness and rollability.

There are some limitations involved in this study. First, the vibrations measured in the previous research were measured at the seat of the wheelchair and may not have been the exact vibrations that were felt by the user. However, the results of Garcia-Mendez et al. showed that the vibrations that most impact the body (between 4 and 12 Hz) could be slightly amplified or dampened by the cushions (Garcia-Mendez et al., 2012). Since there are difficulties with measuring vibrations above the cushions without subjecting the users to harm, we chose the wheelchair frame as the locations, so that it could be easily replicated in the community. Another limitation is that the device used to measure the profile of the surface was a custom built device that is not currently available on the market. For stakeholders to measure and evaluate surfaces based on this study, a device capable of measuring surfaces with the required resolution would have to become commercially available. A standard for calculating PRI would also need to be published by an organization such as the ISO or ASTM International.

Developing any thresholds, such as the one proposed, that will be used by the Access Board will likely be met with some controversy. Historical societies may be resistant to replace old surfaces that have existed for hundreds of years (Boston, MA, is an example; Padjen, 2012). Other individuals or organizations may not like restrictions put on the creativity and artistic design of surfaces to look and feel rough or non-uniform. Contractors and construction companies, and others who would have to build to meet the standard, may also not appreciate the extra regulations. Municipalities, townships, cities, and anyone else responsible for the pathways may not like the limitations that the standard would impose on the various designs and types of surfaces that may be installed. On the opposite side of the discussion, there may be disability rights organizations that believe that the standard does not restrict the pathways enough, and would want all sidewalks to have the same standard design that is most accessible. The proposed thresholds were chosen to be a balance between ensuring that pedestrian pathways are safe and accessible for wheelchair users, while also allowing for other stakeholders to have creative options. As demonstrated in the data obtained from the sidewalks, multiple types of surfaces, including brick, concrete, and asphalt, can be compliant with these thresholds. The non-compliant surfaces also appear to be out of compliance because of a lack of maintenance, rather than because of the original design. Prospective studies of the roughnesses of various surfaces over time could show some insight into which types of surfaces will remain compliant the longest. This could be useful for the people who pay for sidewalks to be installed, in order to get the longest life out of their investment.

In order to determine whether a surface meets the standard, a profile of the surface needs to be measured with a resolution capable of identifying joints between members (ideally 1 mm or less between data points). A standard based on this research is being developed and modeled after ASTM E1926-08 (ASTM International, 2008). A draft of the standard was sent to the Committee on Vehicle—Pavement Systems (E17) of ASTM International for review and balloting. Once a standard is in place and a device that can evaluate a surface to determine if it meets that standard is commercialized, it will take some time for those involved to adapt to the standard. First, anyone planning to install a new surface will need to know whether the surface that they are planning to install will meet the standard. A software package could be developed to predict whether a surface will meet the standard based on installation guidelines and characteristics of the surface members. For example, based on the shape of bricks that will be used and installation guidelines for acceptable horizontal and vertical distance between members, a predicted roughness index could be calculated for that surface.

For existing surfaces, a protocol will need to be developed to determine who, how, and when surfaces will be evaluated. Will contractors and construction workers evaluate the surfaces after they are installed to certify that they were installed in compliance with the standard? How often will surfaces be re-evaluated (annually, bi-annually, every 5 years), and by whom (cities, townships, contractors)? Another consideration to be addressed would be to determine how to eliminate slopes and long wavelength changes in elevation from inflating the roughness of the surface being measured. The surfaces used in this study were uniform and horizontal, which eliminated any bias from slopes.

Conclusion

Previous research results were used to determine appropriate roughness thresholds for pedestrian pathways that are used by wheelchair users. The thresholds proposed use the PRI index and are 100 mm/m for any surface segment of less than 3 m, and 50 mm/m for any surface segments 100 m or more. These thresholds could assist architects, designers and contractors, and city officials design and evaluate whether the roughness of pedestrian pathways are safe and comfortable for wheelchair users.

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Orcid

Jonathan Pearlman  http://orcid.org/0000-0003-0830-9136

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