Comparing Insole Length with Outsole Measurements

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ABSTRACT

SAR resources, including visual trackers, conduct missions for thousands of missing persons every year. These missing persons, who may be wearing footwear, usually own additional pairs. To aid with track interpretation and possibly expedite finding the person, trackers can glean useful information from the other samples.

Relationships between footwear measurements are described for four parameters: insole length, outsole length, outsole width, and heel width. Insole lengths vary less than outsole lengths for individuals. The outsole length, outsole width, and heel width portray linear relationships to insole length with excellent, fair, and poor reliability: R^2 = 0.95, 0.84, and 0.65, respectively. The results of these findings provide footwear dimension predictions and offer benefits for clue interpretation.

KEYWORDS: Search and Rescue, Tracking, Footwear, Tracks, Dimensions

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INTRODUCTION

Thousands of searches for missing persons (also referred to as 'subjects') occur every year in the United States. From 1992 through 2007, the National Park Service alone conducted an average of 4090 search and rescue (SAR) operations per year (Heggie & Amundson, 2009). Countless law enforcement agencies and professional volunteer groups utilized a variety of resources to organize and conduct search efforts for those operations.

Tracking

Visual trackers are often one of the resources involved in organized search efforts, and footprint detection frequently occurs during those searches. Trackers look for footprints and interpret what they or other searchers find. Track interpretations consist of: direction of travel, speed of track maker, age of the track, etc.

Post-detection assessment of tracks includes determining the relevance of the footprints to the search. Just because a searcher finds a track does not mean that the track was made by the missing person. Speiden (2009/2018) states in *Foundations for Awareness, Signcutting, and Tracking*, "Not all sign will be relevant to the missing person." As with any other potential clue found during the search effort, trackers should analyze footprints for likelihood of association with the subject. This assessment can rule out irrelevant tracks and prevent a waste of resources spent by assuming that a found track means that it was made by the missing person.

Research is being conducted on clues found during search efforts. Preliminary findings from 503 searches indicate that subjects' footprints were found on 84 (17%) of those searches. Of those 84 searches, tracks were found by trackers on 56 (67%) of them, non-trackers found tracks on 16 (19%) of the searches, and the tracking training of the searchers that found tracks on the remaining 14% of searches was not recorded (Speiden, 2024). If these numbers are extrapolated to the annual average of 4090 searches that occur in US national parks alone, that suggests that trackers could find tracks on over 450 searches per year. While that is a very speculative number, it is nonetheless a hint at how significant a role tracks can play in pointing searchers towards the missing person. Even if trained and certified trackers aren't assisting with a search, clue-aware searchers, by the same speculation, are likely to find tracks on hundreds of searches per year.

One factor used to assess the likelihood that the subject made a track of interest is the measurements of the track itself. Information about the dimensions of tracks assists trackers in determining tracks as either pertinent or unconnected to the search effort.

Subject's Footwear

Gathering subject information is typically one of the first tasks in an organized SAR mission. Koester (2008) writes in *Lost Person Behavior,* "Investigation is the tool that helps determine the specifics of an individual." Among many other bits of useful information (e.g., clothing they are reported to be wearing), search resources can generate intelligence about the missing person's footwear through investigations.

The subject's contemporary footwear (if indeed they don footwear) typically remains absent during the search phase of SAR. However, most subjects possess additional, accessible footwear which may aid searchers.

Narrowing the possibilities of probable measurements challenges even the best trackers. Determining the likely or probable range of measurements of a particular subject's tracks is a difficult task. Discovering useful information requires a diligent effort. Track dimensions can be compared with the subject's other footwear to determine if a track of interest is too small, too large, or is one that could reasonably have been made by the subject. Knowledge of a missing person's footwear dimensions can aid track interpretation, and potentially accelerate finding the person.

A question about variation among insole and outsole lengths arose early in this process. That question was "Which, if either, varied more among all footwear belonging to an individual – their insole or outsole measurements?" The answer to that question would determine which dimension would be recommended as a reference for predicting the dimensions of tracks made by the missing person.

LITERATURE REVIEW

A literature search using the terms insole, outsole, footwear, dimensions, and/or relationship in PubMed, ScienceDirect, Semantic Scholar, Google Scholar, JSTOR, and ResearchGate yielded no publications or studies of relationships between footwear insole and outsole dimensions.

Recent publications describe tools being developed for the advancement of insole pressure measurements for sports (Krüger & Edelmann-Nusser, 2009) and fall risk assessment (Subramaniam et al., 2022), as well as an outsole measurement tool for slip prevention (Whitson et al., 2018).

Giles and Vallandingham (1991) discuss relationships between foot, footwear, and footprint measurements with regard to a persons' height but do not include footwear insole measurements or specific outsole measurement techniques.

Forensic descriptions of insole investigations focus on comparing identifying features found on insole surfaces with those of inked impressions from suspects' feet, but there is no mention of any relationship to outsole dimensions (Abbott & Germann, 1964), (Bodziak, 2000), (Bodziak, 2017), (Cassidy, 1980).

Many websites show how to determine the size of a shoe based on foot measurements, but none were found that discuss the comparison of the insole to outsole measurements.

METHOD

Individual variations

Insole lengths and outsole lengths were measured with a 17mm-wide tape measure for multiple pairs of footwear from each of five individuals. The sample size from the five individuals consisted of 7, 8, 14, 20, and 22 items of footwear for a total of 71. The range of lengths was then calculated by subtracting the shortest length from the longest length.

Insole outsole dimensions

In an attempt to reflect typical footwear missing persons were found wearing, a variety of footwear such as minimal shoes (e.g., flip flops), sneakers, and boots was included. Steel or composite-toed footwear, high-heels, novelty shoes, and other specialized footwear were excluded since they were not found with missing persons (Speiden et al., 2024).

Measurements of three hundred pieces of footwear yielded four data points for each piece: Insole Length, Outsole Length, Outsole Width, and Heel Width.

The **insole length** was measured by inserting a 17mm (½") wide tape measure into one item (right or left) of each pair of footwear with the leading edge of the tape measure pushed to the front of the toe. The tape was held flat against the floor of the insole. The tape was then bent at the rear edge or rise of the heel (See Figure 1a). The reading at the heel was made as closely as possible to the point at which the rise (vertical slope) equaled the run (horizontal aspect). The measurement was read and recorded to a precision of 1mm with an estimated error of ± 2mm due to curvature at the heel.

The **outsole length** was measured by hooking the tape at the front of the outsole and reading the length at the back edge of the heel (See Figure 1b). When measuring a rounded or sloped edge, the length was read as the distance between the two closest points where the rise equaled the run.

The **outsole width** was measured at the widest part of the footwear, in the ball area of the footwear. The authors used this preferred measurement location vis a vis their observations on real-world searches that formed part of a previous study (Speiden et al, 2024). All footwear worn by subjects documented in that study was widest at the ball portion of the sole. To measure the outsole width, the tape measure was hooked on one side of the outsole then the width was read at the opposite edge of the outsole (See Figure 1c). The distance between the two closest points where the rise equaled the run yielded the measurement for outsoles with rounded edges.

The **heel width** was measured at the widest part of the heel or rear portion of the outsole. Hooking the end of the tape measure on one side of the heel then reading the width at the opposite edge of the shoe provided this measurement (See Figure 1d). The distance between the two closest points where the rise equaled the run yielded the measurement for outsoles with rounded edges.

Figure 1: *Footwear measurements from left to right: (a) Insole Length (b) Outsole Length (c) Outsole Width (d) Heel Width.*

RESULTS

Individual Variations

Figure 2 shows the range of insole and outsole lengths for the five individuals. Insole length ranges varied from a minimum of 17mm to a maximum of 40mm with an average of 28mm. Outsole length ranges varied from a minimum of 32mm to a maximum of 51mm with an average of 41mm. The average outsole lengths varied 13mm (46%) more than the average insole length range.

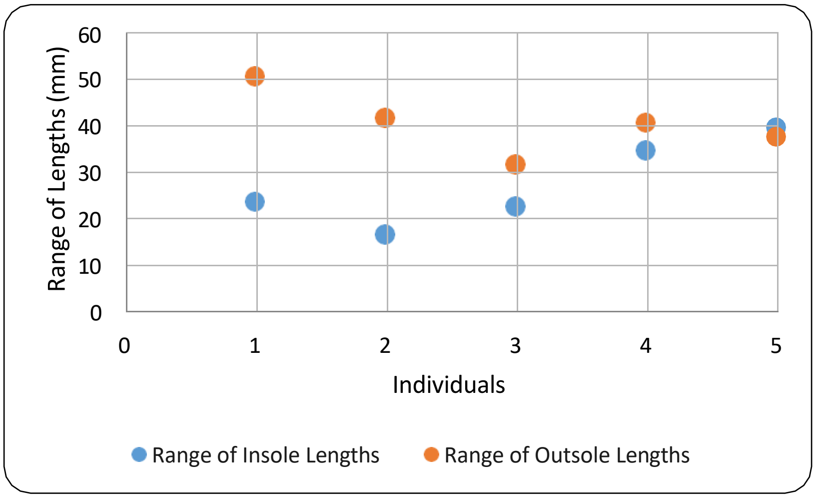

Figure 2: *Individual Insole and Outsole Length Variations*

Insole Outsole Dimensions

Outsole measurements (outsole length, outsole width, and heel width) were analyzed with regard to the insole length. The insole length was utilized as the independent variable. Outsole length, outsole width, and heel width all exhibited positive linear relationships with respect to insole length, as shown in Figure 3.

The minimum and maximum values for the insole length were 105mm and 337mm, respectively. The minimum and maximum values for the outsole length were 121mm and 372mm, respectively. The minimum and maximum values for the outsole width were 63mm and 135mm, respectively. The minimum and maximum values for the heel width were 43mm and 110mm, respectively. The outsole length displayed a notably higher contiguous increase than the two widths. Due to a larger variation in the outsole lengths than either of the width measurements, the researchers expected this discrepancy, (Table 1).

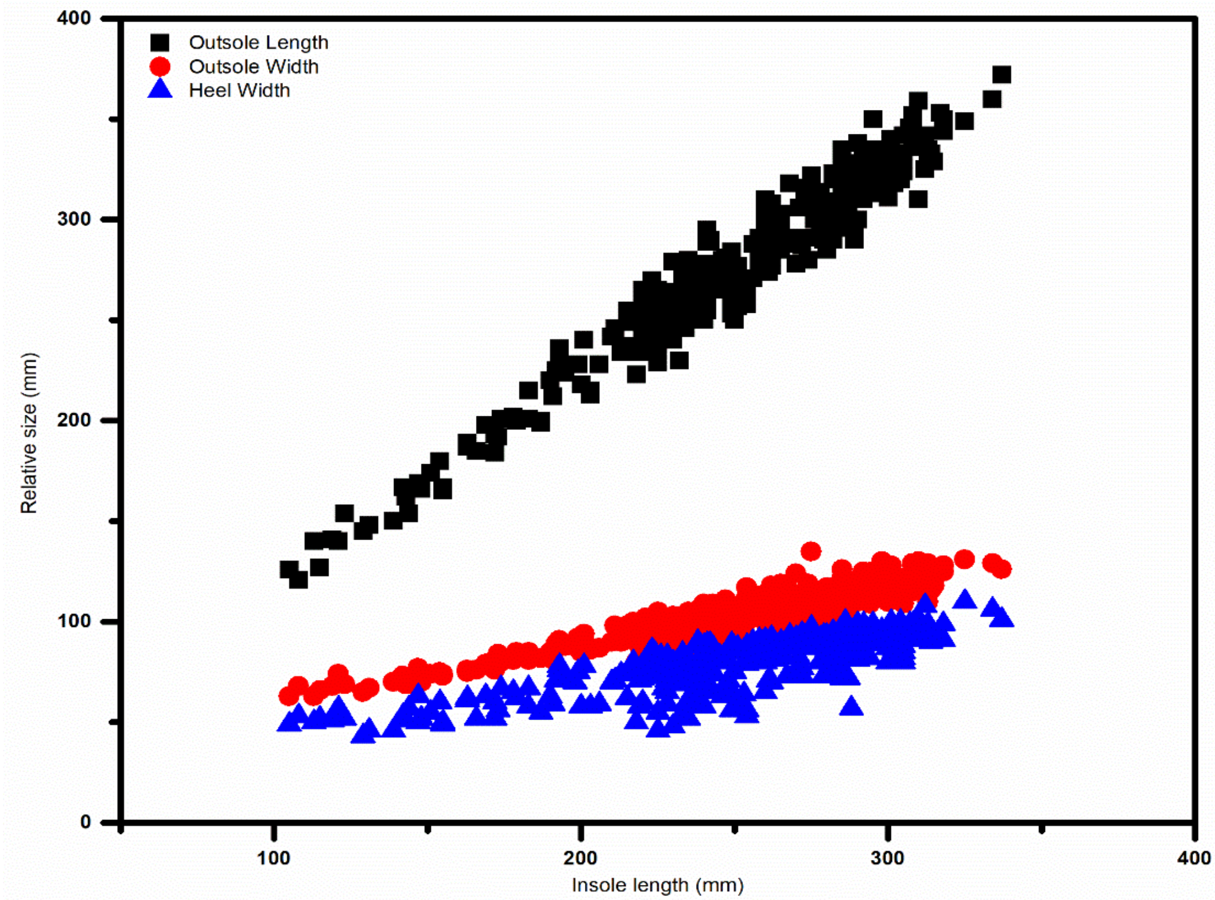

Figure 3: *Plot of data collected for insole length and associated outsole measurements overall length, overall width, and heel width.*

Linear modeling

The linear relationship was analyzed with the sum of least squares fit between the insole length versus outsole length, outsole width, and heel (see Table 1). The equation produced for the outsole length exhibited the highest R^2 value of 0.95, followed by the outsole width and heel width models which yielded R^2 values of 0.84 and 0.65, respectively.

Introducing a 21mm margin of error (L_O = 18mm + 1.03 x L_I ± 21mm) (where L_O = outsole length and L_I = insole length) encompassed a 95% confidence interval for the relationship between insole length and outsole length. The 95% confidence interval ($p<0.01$) included a range of the resultant outsole length value of that equation, plus or minus 21 millimeters (0.83 inches).

In addition to a range that varied from -3mm to +39mm (-0.1" to +1.5"), 95% of measured outsole lengths included 1.03 times the insole length. For both the outsole width and heel width, however, the poor fit model suggests that, when compared to the insole length, such dimensions are unreliable for predictable values.

Dimension	Minimum	Maximum	Linear equation	R^2	95% PI[a]	95% CI[a]	90% CI[a]
Insole length	105	337	-	-	-	-	-
Outsole length	121	372	$L_O = 18 + 1.03L_I$	0.95	21	16	11
Outsole width	63	135	$W_O = 29 + 0.295L_I$	0.84	30	-	-
Heel width	43	110	$W_H = 18 + 0.250L_I$	0.65	20	-	-

[a] value is given for ± of the L_I-intercept in mm

Table 1: *Data values and linear models for insole length (variable L_I) compared with outsole length (L_O), outsole width (W_O), and heel width (W_H) including prediction intervals (PI). All units are in millimeters.*

DISCUSSION

Individual variations

Of the five individuals sampled for the range comparison, for four of them, the outsole lengths varied more than the insole lengths. With regard to the one individual for which the insole lengths varied more than the outsole lengths, the discrepancy was the smallest among all of the individuals at a mere 2 mm. The comparison of insole and outsole length measurement ranges between five individuals showed a clear, though not absolute, propensity for outsole lengths to vary 46% more than insole lengths. This demonstrates that the insole length is more reliable than the outsole length for use as an independent variable in predicting track dimensions.

Relationship of insole and outsole lengths

By applying the outsole length linear model $L_O = 18 + 1.03L_I$, the median value for an outsole length should be between 21mm and 28mm greater than an insole length. In order to display the probability of outsole length, measurements of outsole length minus insole length were subdivided into 12 groups of five mm increments: 0-4mm, 5-9mm, 10-14mm, etc. The distribution closely fits a normalized Gaussian probability distribution (see Figure 4). The maxima resided at 26mm, which indeed corresponds to the previous linear model prediction as well.

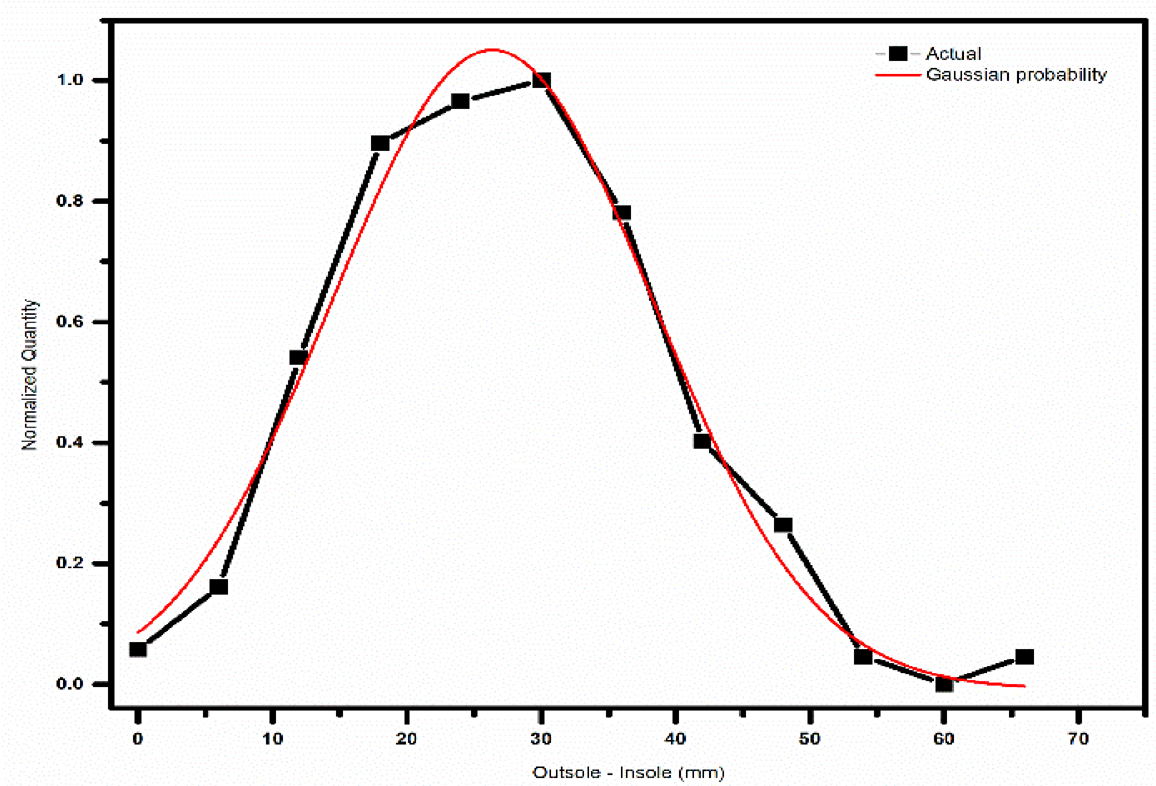

Figure 4: *A normalized distribution of outsole length less insole length for the body of samples measured. The black line represents the actual data measured. The red line represents the modeled distribution of the data.*

The probability distribution highlights the likelihood for real-world applications. Probability for footwear with zero difference in outsole to insole remains very low. Footwear types such as high heels and wedge shoes, however, do exhibit a zero or even negative differential value. Since those types of footwear have not been documented in missing persons cases (Speiden et al., 2024), they were excluded from this research. For the confines of this study, the 95% probability for differential lengths resides between 4mm and 51mm (see Figure 5).

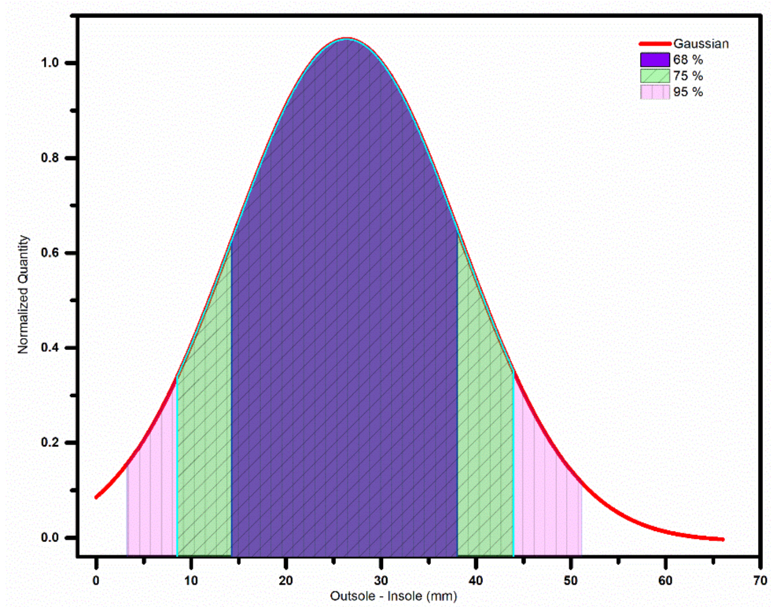

Figure 5: *Normalized distribution with prediction probability bands for 68%, 75%, and 95% overlaid.*

Comparing dimension relationships

As a comparison of the three resulting dimensions which are predictable based on the insole length (outsole length, outsole width, and heel width), the most reliable with the smallest range is the outsole length. This data suggests, as a result of the R^2 values (Table 1), that there are larger margins of errors in predicting the width of the sole or heel based on the insole measurement.

Furthermore, the field application for trackers would benefit from larger dispersion of values for prediction measurements. A small change in search values (outsole length, outsole width, and heel width) which the tracker will be evaluating would ideally change with insole length inputs. To illustrate this, Figure 6 shows the effects of different insole lengths for prediction values in resultant measurements.

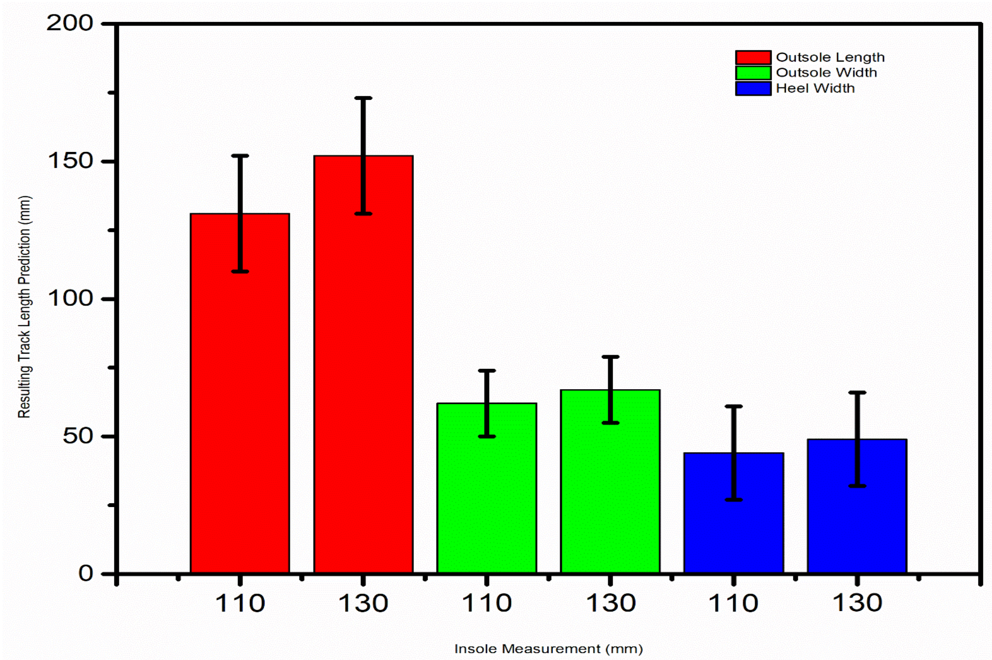

Figure 6: *Graph showing overlap of prediction band changes with a difference between insole length measurements*

As an example, Figure 6 shows the difference in predicted values with a 95% prediction band for outsole length, outsole width, and heel width. The larger the overlap of the error bars means the lower the distinguishing ability for trackers in the field. Note that the smallest amount of overlap exists for the outsole length based on the two different insole measurements of 110mm and 130mm. Based on both the R-squared values and the larger differentiation of prediction values, outsole length has the highest reliability for determining potential versus non-potential tracks of interest. Therefore, the outsole length versus insole length regression with the 95% prediction band provides the highest utility among all of the outsole dimensions for trackers and rescuers (Figure 7).

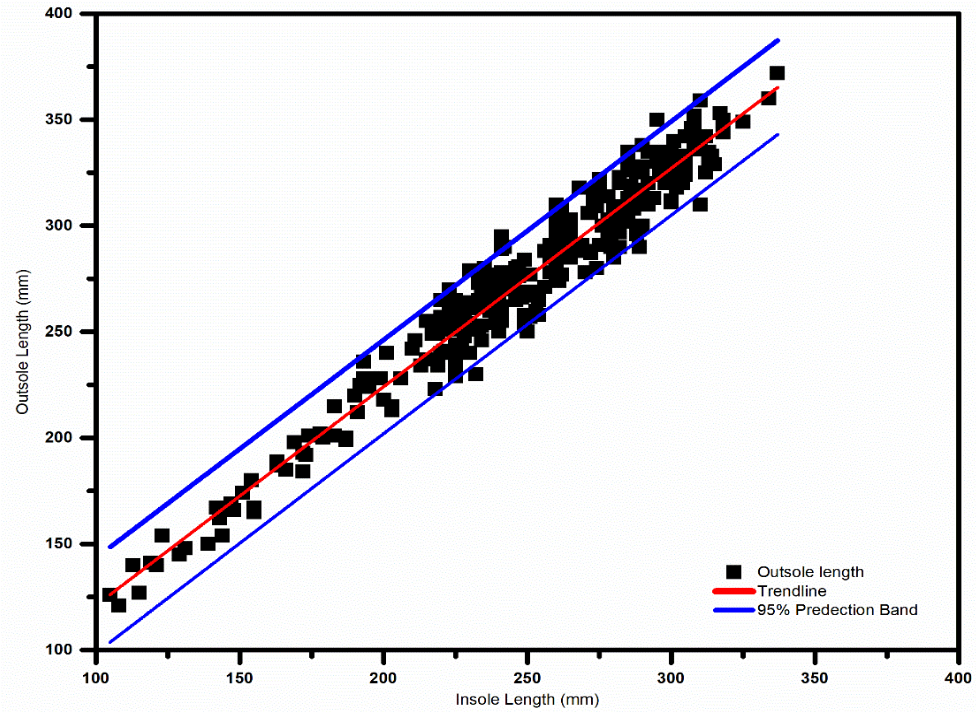

Figure 7: *Linear modeling of the outsole length versus insole length with upper and lower 95% prediction bands for footwear with insole lengths between 105 and 337 mm*

Insole measurement alternative

Another method of measuring the insole length is to remove the insole from the footwear and then measure it. The advantages of this technique include the reduction of error from the size of the tape measure, as well as the ability to measure the overall width and the heel width. There may be a sensitive issue with the act of taking apart a missing person's footwear in front of the family who is likely already distressed. Reducing that potential awkwardness may be as easy as asking permission to measure the insoles, which can be facilitated by offering a simple explanation of the reasons for the intrusion. Removing the insole and gathering these measurements can also be completed out of view of the family members. Other circumstances (e.g., not all insoles are removable) may also present difficulties related to externally measuring insoles. Nonetheless, insole length determinations often require internal measurement.

CONCLUSIONS

Thousands of searches for missing persons occur worldwide each year. Myriad resources, including visual trackers, assist with searches for missing persons. As part of a tracking team that wants to find and follow tracks made by the missing person, trackers' initial goals are to seek, locate, and interpret tracks. They should also be able to rule out tracks made by people who are not missing (unless another person was involved in the subject's disappearance). Necessary interpretations of tracks of interest include their relevance to the search effort.

In the absence of any information about the subject's shoes, challenges arise while sorting out the subject's tracks from those of anyone else. These challenges include searchers walking around the search area. Having some information about the subject's footwear helps narrow possible tracks via a process of elimination.

In the quest for footwear information, the insole lengths were determined to vary less than outsole lengths for a variety of footwear owned by individuals. Four distinct measurements from 300 pairs of footwear were then gathered and analyzed. Those measurements consisted of insole length, outsole length, outsole width, and heel width. The strongest correlation exists between the insole length and the outsole length. The focus of this study was on developing a base of information that could help interpret tracks that may have been left by, and therefore lead to, a missing person.

No prior research or publications on this topic was discovered. This research provides a scientific understanding for tracking via track interpretation in future search missions and offers a foundation for additional studies relative to this topic.

Even though it is not possible to measure footwear the subject may be wearing, the measurements of other footwear belonging to the subject can give valuable information. Additional research shows the relationships between the insole length(s) of footwear and the owner's foot size (for unshod cases) and footwear (for shod cases). Although missing persons often lose their footwear, key footwear information can also indicate probable measurements of unshod (barefoot or sock-clad) footprints (Speiden & Serrano, 2024).

Using the model developed in this research, any track of interest may be quickly assessed as plausible or improbable based on the relevance to the missing person. Based on this study, trackers may apply a simple field method for assisting in tracking missions. Trained trackers are advised to measure the insole lengths of three pairs of footwear belonging to a missing person (minimum of one is required).

Using the length of an insole provides a 47mm (2") window of probable outsole lengths. The window of probabilities can therefore be used to include or exclude outsole lengths and track lengths found on a missing person search. This flow-chart (Figure 8) assists with drawing conclusions and potentially serves as a feasible field practice for visual trackers.

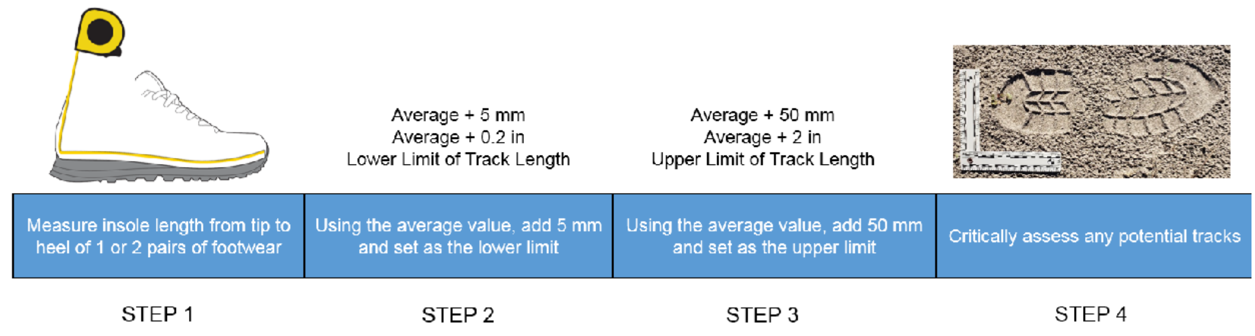

Figure 8: *Flow chart for process of incorporating the findings of this study into practice*

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RESEARCH LIMITATIONS

The footwear measurement data included in this study were collected by measurements with a tape measure. While more precise and accurate methods are available, the tape measure is the tool that trackers most consistently use to get footwear and track measurements during search operations.

Due to lack of reported prevalence with some types of footwear (e.g., wedges, high heels, etc.), this study excluded those in research of footwear worn by missing persons (Speiden et al., 2024). These exclusions tended to exhibit outsole lengths shorter than insole lengths. Should a missing person be known to wear any of these types of shoes, it is recommended that consideration be given to adjusting the range of shod track length.

The comparison of the length of a track to footwear dimensions requires a complete track. Partial tracks are typically found more often than complete tracks, but a full track length is necessary for an accurate comparison with footwear measurements.

ADDITIONAL RESEARCH

To increase the rigor of the results, an additional study recommendation is to gather more data similar to this study. Practical applications of this research include two avenues. This study narrows the possibilities of dimensions of tracks made by footwear that missing persons are wearing. This study can guide further research regarding dimensions of missing persons' footwear and dimensions of associated footprints. As mentioned in the introduction, research is also being conducted to gather data on clues found at searches.

Research related to this paper is underway and encompasses several topics. Those topics include insole measurements with tape measures that have different hook areas, as well as correlations between insole length and track dimensions. Research that describes relationships between insole length and unshod foot length, as well as insole length and shod footprint length is currently being written. Research is also being done to describe changes to the dimensions of footwear measured in this study compared with age of footwear, be that age time or distance that footwear has been worn.

ABOUT THE AUTHORS

Robert "Rob" Speiden holds a bachelor of science in engineering degree from Virginia Tech. He is an active member of the SAR community and has assisted with well over 450 searches since 1993. As a member of several SAR groups, Rob responds to searches in the mid-Atlantic region of the U.S. serving the roles of certified Tracking Specialist, Search Team Leader, and Search Mission Coordinator.

Rob has been an instructor and evaluator for the Virginia Department of Emergency Management (VDEM) since 1998. He is also certified as a Trailing Evaluator for Cybertracker Conservation. As the VDEM Lead Tracking Instructor, and through his Natural Awareness Tracking School, he teaches map/compass/GPS skills, Lost Person Behavior, and Tracking classes (for humans and other animals) to search and rescue volunteers, law enforcement officers, and government agents around the world. Rob has authored and published three SAR tracking books: *Foundations for Awareness, Signcutting and Tracking*, *Tracker Training*, and the *Pocket Guide to Human Tracking for SAR*.

Joel Serrano earned his Ph.D. degree in Chemistry from Virginia Tech. He is an EMT and Search Team Leader with the Blacksburg Volunteer Rescue Squad. Joel is an Operational Tracker with the Search and Rescue Tracking Institute, and he is certified as a Level I Tracker in the Cybertracker Conservation program. Through the scientific lens, Joel seeks to alleviate human suffering, if even only for a moment.

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