

Human Factors Topic: Biomechanics, Anthropometry, Work Physiology

Modeling Occupational Fingernail Onycholysis Disorders in the Population of US Astronauts Who Have Engaged in Extravehicular Activity

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Running Title: Onycholysis in astronauts after EVA

Manuscript Type: Research Article

Number of words: 5,312

Acknowledgements: The authors thank Millennia Young and Caroline Schaefer of NASA's Lifetime Surveillance of Astronaut Health who assisted with the statistical analysis of the study. Additionally, we express sincere gratitude to Scott Cupples of the NASA JSC EVA Flight Office, who provided historical insight into the contextual changes and uses of EVA gloves over the three decades this study covered. Lastly, the authors thank Jane Krauhs for technical editing of the submission.

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Conflict of Interest and Funding: The authors declare no conflict of interest. Funding was provided by the NASA Human Research Program's Human Health and Countermeasures Element. The study sponsor had no specific involvement in the study design, data analysis, manuscript preparation, or decision to submit the manuscript.

Abstract

Objectives: Spacesuits are designed to be reliable personal spacecraft that preserve the life and well-being of the astronaut from the extremes of space. However, materials, operating pressures, and suit design requirements often result in a risk of musculoskeletal discomfort and injury to various areas of the body. In particular, this investigation looked at fingernails and their risk of developing onycholysis.

Methods: An onycholysis literature review was followed by a retrospective analysis of injury characteristics, astronaut suited training and spaceflight events, hand anthropometry, glove sizing, and astronaut demographics. Multiple logistic regression was used to assess the likelihood of onycholysis occurrence by testing potential risk variables against the dataset compiled from the retrospective data mining.

Results: The duration of event exposure, type of glove used, distance (delta) between the fingertip and the tip of the glove, sex, and age were found to be significantly related to occurrence of onycholysis (whether protective or injurious).

Conclusion: An initial risk formula (model) for onycholysis was developed as a result of this investigation. In addition to validation through a future study, further improvement to this onycholysis equation and spacesuit discomfort and injury in general can be aided by future investigations that lead to better definition of the threshold between safe and risky exposure for each type of risk factor.

Application: This work described a potential method that can be used for EVA spacesuit glove onycholysis injury risk analysis for either iterative glove design or between glove comparisons, such as during a product downselect process.

Keywords: spacesuit, occupational injury, glove, mathematical modeling, data mining

Précis: Onycholysis injury data of astronauts can inform the design of extravehicular activity space suit gloves. Several mitigation areas are indicated by the study, but limitations in the data prevent clear application of new guidelines without more robust and consistent data collection of these key variables.

Introduction

In 1965, Edward White was the first US astronaut to perform an extravehicular activity (EVA) for the National Aeronautics and Space Administration (NASA) (NASA, n.d.). As of the completion of this study's investigation (2014), the US had conducted more than 400 EVAs from several different spacecraft. During EVAs, astronauts must wear gas-pressurized spacesuits to protect their bodies from the harsh conditions of space. Although these spacesuits are effective in keeping astronauts alive, they are known to severely limit human performance (i.e., by reducing joint mobility and strength) (Amick, et al., 2015; Gonzalez, et al., 2002; Morgan, et al., 1996; Reid, et al., 2014) and pose a risk of musculoskeletal discomforts and injuries (Anderson, et al., 2012; Anderson, et al., 2015; Charvat, et al., 2015; Opperman, et al., 2009; Scheuring, et al., 2009; Strauss, 2004; Strauss, et al., 2005; Williams & Johnson, 2003).

EVA Spacesuit Gloves

Although the most notable EVAs were conducted on the Moon during the Apollo program under reduced gravity, the vast majority of EVAs have been conducted in microgravity, which requires astronauts to use their hands for the entire duration of the EVA. This requires that EVA gloves be constructed robustly to prevent wear-and-tear damage, but also be flexible enough to allow astronaut hands to manipulate tools, handrails, and other hardware interfaces. Gloves are a common item of personal protective equipment used in many work environments across most industries. Their efficiency of design is gauged by their ability to provide optimal protection while still enabling wearers to perform their work with minimal hindrance. Customization to the task and the fit of the wearer population are key to a good fusion in the body-glove relationship. This naturally complex design process for Earth-based protective gloves is further complicated by the fact that spacesuits, including their gloves, are inflated using air pressure, which is required to prevent ebullism, decompression sickness, and hypoxia in the vacuum of space.

The construction of EVA gloves is complex, with each glove containing a minimum of four layers of garment material: the innermost layer to the hand is a comfort garment, next a pressure bladder layer, then a restraint layer, and finally the thermal micrometeoroid garment (TMG) outer layer, which itself is constructed of several layers of materials. When in its nominally pressurized state, the inner pressure bladder will inflate and stiffen, requiring an increase in muscular effort to manipulate the glove. To help counter this deficiency, engineers design the gloves to have a restraint layer on the outside of the bladder layer to create articulation points along the bladder that allow the hand joints to move. These combined restraint and bladder layers, in combination with glove gimbals and bearings, are ideally aligned with the joint centers of the spacesuit user's hand while balancing tightness against the skin at the fingertips and finger crotches to allow optimal fit and tactility. The glove then connects to the spacesuit with the arm and torso segments to ensure the hand stays in the correct alignment within the glove. The astronaut must learn to get into the proper orientation to perform the necessary EVA tasks and maintain that correct position for EVAs lasting up to 8 hours in microgravity and up to 6 hours in Earth gravity (ground)-associated training neutral buoyancy swimming pool sessions (with 10 or more trainings per mission). It is because of these multiple layers of material, along with the atmospheric pressurization factor, that astronauts experience a loss in hand mobility, strength performance, tactility, and overall manual dexterity. Combining this loss of performance with hours of use in both training and spaceflight EVA raises a significant risk of hand-related injury.

Onycholysis Literature

Onycholysis is the gradual separation of the fingernail from the nail bed and is one of the most common types of hand injuries seen among astronauts, particularly to that of the middle finger (Charvat, et al., 2015). In the general population, onycholysis can occur for a wide variety of reasons, some of which may be more relevant to the occurrences in the astronaut population. Repeated trauma may be a factor in onycholysis (Baran & Badillet, 1982; Samman, 1979), as a result of repeatedly pulling off artificial fingernails (Calnan & Sarkany, 1958), prying open walnut shells ("nutcracker nails") (Cohen, et al., 1975;

Wilkinson, 1985), or skinning or removing fat from slaughterhouse animals (Baran, et al., 2012; Moore & Garge, 1997). According to Cohen (2008), “harpist finger” is a complaint of musicians who pluck strings; with this condition, onycholysis sometimes accompanies paronychia (skin infection around the nail) and subungual hemorrhaging (bleeding under the nail). On toenails, onycholysis is often blamed on mechanical trauma, whether from contact with shoes or between adjacent toes, especially in poorly fitting shoes. The problem of toenail loss, frequently with subungual hemorrhaging, plagues athletes (Burkhart, 1999) and ballet dancers (Shah, 2010), both of whom put extreme stress on their toes. Moisture exposure is another risk factor for onycholysis, and can often occur along with mechanical stress during certain types of work or with sweat accumulation (Adams, 1985; Sharquie, et al., 2005). In at least one case in the literature, onycholysis was believed to result from persistent pressure on the pads of the fingers (Mosannen-Mozafari, et al., 2011). In another case, restriction of blood flow was believed to be the cause of onycholysis (Cabanillas, et al., 2011).

Other causes, but less attributable to EVA suited exposure, include allergic reactions to contact irritant such as the free formaldehyde in nail hardeners (Baran & Kechijian, 2000; Barnett & Scher, 1992). Nail hardeners have recently been reformulated in the US to omit large quantities of free formaldehyde (Barnett & Scher, 1992) since it is estimated that 8-9% of the population has a contact allergy to formaldehyde (de Groot, et al., 2009). However, the US Food and Drug Administration still reports allergic reactions to even modern nail hardeners (Food & Drug Administration, 2020). Onychomycosis is a fungal infection of the nail plate, nail bed, or both. Onychomycosis can be the cause of nail separation, but it can also thrive secondary to nail separation, in the space below the lifted nail, making it difficult to determine etiology (Baran & Badillet, 1982; Sharquie, et al., 2005). Other causes of onycholysis included psoriasis, which usually involves multiple nails (Sehgal, et al., 2011; Tosti, et al., 2009), thyroid dysregulation (Ghayee, et al., 2005), and introduction of foreign bodies under the nail (Adams, 1985).

Despite glove model evolutions and the performance gains achieved by NASA since the first EVA in 1965, hand injuries induced by EVA gloves have continuously persisted. This makes the nature and causation of injury of particular interest to spacesuit engineers involved with current and future EVA spacesuit glove designs. The purpose of this investigation was to explore the prevalence of fingernail onycholysis (separation of the fingernail from the nail bed) and to better understand the factors associated with the occurrence of this injury. This study included a comparison of injuries with the Phase VI glove (the current EVA spaceflight glove) and the Series 4000, a glove model that was flown prior to the Phase VI glove.

Study Population and Methods

This paper was a secondary analysis from a larger retrospective EVA glove injury data mining investigation conducted between 2012 and 2014, which focused on three decades of EVA training and spaceflight data. The goal of the larger study was to conduct a broad injury assessment of all injuries that occurred to the upper extremities between the fingernails and the elbow (Charvat, et al., 2015). Fingernail onycholysis injuries are the outcome of interest for this analysis because of their severity and greater prevalence than most other upper-extremity injuries experienced by NASA astronauts. Onycholysis is the partial separation of the fingernail plate from the nail bed or complete nail plate loss. This study was reviewed by the Johnson Space Center Institutional Review Board as Pro0854 and was approved as exempt.

This study was an observational historical cohort analysis. Data used in this analysis were injury outcome, anthropometry, EVA glove series and sizing, and event data from training and spaceflight records. The study focused only on US astronauts who utilized the Series 4000 or Phase VI gloves while in the extravehicular mobility unit (EMU) spacesuit. With its ultimate intent being to develop an ergonomic guideline for developing EVA gloves, this study’s initial objectives focused on the nature and potential causative factors of injury while wearing EVA gloves and were accomplished through both descriptive and predictive statistical analysis.

Onycholysis Literature Search

External literature was consulted to assess how the injuries listed from the EVA data may have been applicable to non-astronaut populations outside of NASA. This task included finding literature related to the etiology and pathophysiology of onycholysis. An additional step was taken to determine whether any potential surrogate populations exist outside of NASA that may have been experiencing similar injuries. Investigators utilized online search tools such as Google Scholar, WebMD, eMedicine, PubMed, and Science Direct. Literature types included websites, books, journals, and conference papers, as well as archived personal interviews. The US Bureau of Labor Statistics 2011 data were also reviewed by investigators to understand the prevalence of the different injuries in astronauts relative to other industry populations. Unfortunately, onycholysis was not an injury prevalent enough in these other industries to be captured by the Occupational Safety & Health Administration (OSHA), so its results were not included for this study.

Study Sample

As of 2020, a total of 350 people have been selected as US astronauts. Of these, 224 served as active-duty astronauts between 1981 and 2010, and 179 of these had at least one recorded EVA training or spaceflight event and are included in this analysis.

Study Variables

Dependent Variables

The dependent variable of interest was if an onycholysis injury occurred in the astronaut (yes or no) during a training or EVA event. These injuries were determined from several sources including the NASA Johnson Space Center (JSC) Electronic Medical Records (EMRs), post-spaceflight Space Shuttle medical debriefs, private medical conferences between astronauts and their crew surgeons (ISS-based records), and Suit Symptom Surveillance Questionnaires. To add context to each reporting incident, specific data including type of injury, specific body location, injury characteristics, countermeasures utilized by astronauts, and any anecdotal comments were collected.

Independent Exposure Variables

Candidate independent exposure variables were analyzed with respect to their relationship to the injury outcome. These included several variable types: demographic variables, hand anthropometry, glove sizing, training and spaceflight event characteristics, and injury-specific information (Table 1).

Table 1. Independent Exposure Variables

Data attribute	Variable
Demographic data	Sex, age
Hand anthropometry data	Finger proximal interphalangeal joint (IP) circumferences, finger length, hand breadth, hand circumference, hand length, dominant hand.
Glove sizing data	Phase VI: middle-finger length, middle-finger proximal IP circumference, hand length, hand circumference. Series 4000: middle-finger length, hand circumference. Difference (delta) between the hand anthropometry and the corresponding measurements of the baseline glove ("glove size").

Because the number of injuries was low relative to the large number of spaceflight and training events, the potential for each of the 26 anthropometric measurements (10 finger circumferences, 10 finger lengths, two hand breadths, two hand circumferences, and two hand lengths) to be associated with injury was low. Also, the individual anthropometric measurements were highly correlated among each other (correlations ≥ 0.5), indicating a high likelihood that the statistical model would not converge. Therefore, the individual anthropometric measurements were combined based on the results of a principal component analysis (PCA), to create a single variable that was used in subsequent regression analyses.

In addition to anthropometry data for both hands, investigators gathered EVA Phase VI and Series 4000 glove sizing records, which were provided from EMU suit technicians (Stinger Ghaffarian Technologies), and mission training and spaceflight records. In total, 12,026 EVA glove records were assessed, of which 322 were related to spaceflight EVA and 11,704 to ground-based EVA training. A large proportion of glove sizing data were missing (approximately 28%). Of the 12,026 training and spaceflight events analyzed, glove data were missing from 3,328 events. If a glove model could be deduced from what was worn before and after a missing event, the missing glove model was replaced. This replacement method completed 2,500 of the 3,328 missing glove model data deficits. Because glove sizing measurements are very specific to a particular glove, it was not feasible to use standard replacement methods to impute sizing measurements; therefore any analyses that used glove sizing measurements had a reduced sample size. Each glove size is based on measurements of certain anthropometric characteristics of the hand. These sizing measurements were related to the specific anthropometric characteristics of the crewmember to identify a “delta” between the sizing of the glove and the anthropometry of the crewmember. The Phase VI glove size is derived from four measurements per hand: hand circumference, hand length, middle-finger length, and middle-finger circumference. The size for the Series 4000 glove is based on only two measurements per hand: middle-finger length and hand circumference. Because of the high correlations between the deltas for left and right hands on each measure ($r > 0.7$), only the delta between the glove size and the anthropometry for the dominant hand was used in the regression models. In cases where the glove sizing was unknown, this delta was not included in the analysis.

Training and EVA event information were also included in the analysis. This information consisted of the type of event (training or spaceflight mission) date, duration, and frequency of events per month. Missing training times were replaced using the mean of all available training times. There were no missing spaceflight times.

Control Variables

Two variables were used as control variables in the statistical models; training between 2002 and 2004 and spaceflight versus training. After conception of the study, investigators learned that several endeavors during the 2002-2004 time period created an over-reporting of injuries, the Prospective Suit Symptom Study (Strauss, et al., 2005) and the Shoulder Injury Tiger Team Research study (Williams & Johnson, 2003). Therefore, an indicator variable signifying that the training occurred during this period is included to control for these reporting differences.

Previous injury analyses have been stratified by the type of event in which the crewmember was participating in, whether training or spaceflight EVA. This made possible an understanding of independent exposure variables as they relate to each type of event (Charvat, et al., 2015). For this onycholysis analysis, knowing whether an event occurred during spaceflight or training was required to account for the low number of onycholysis injuries reported during EVA.

Predictive Statistical Analysis

All predictive statistical analyses were performed using SAS 9.3 (SAS Institute, Cary, NC). This exploratory study was conducted to understand factors that may be related to onycholysis during training and spaceflight suited exposures. The relationship between the outcomes of onycholysis injury (yes or no) and candidate independent variables was analyzed using multiple logistic regression analyses. Repeated

observations within the same individual were adjusted by using generalized estimating equations in fitting the underlying logistic regression model. The initial analysis started with a “Full Model,” including all candidate independent exposure variables, and moved toward a “Parsimonious Model” that included only independent exposure variables that were significant at the $p < 0.15$ level. For this exploratory analysis, the $p < 0.15$ level was chosen for retaining independent exposure variables to not exclude variables that might be important but that, because of the small sample size of onycholysis injuries relative to the number of exposures, would not be detected at the typical $p < 0.05$ statistical significance level.

Results

Descriptive Analysis of Onycholysis Injuries

There were 27 training-related onycholysis incidents and four incidents that occurred during an EVA among 22 US astronauts (4 women, 18 men). Among the training injuries were several incidents of pain associated with onycholysis, and a few descriptions of discolored nails (red or bruised proximal nail beds, and pale distal nail beds). For this study’s astronaut test sample, onycholysis seemed to affect the nails of the fingers more than the thumb, with the highest incident count on the middle finger. Anecdotal comments on the “causes” of training injuries included several contact-related complaints such as “glove too short” or “axial loading of gloves on fingertips with forceful gripping,” and one mention of moisture “from sweating.” One spaceflight incident mentioned “pressure in fingernails” associated with the injury.

Countermeasures included using a nail hardener, resizing gloves, and clipping fingernails back. A distribution of these injury data can be seen in Table 2, where the injuries are shown according to different exposure or individual characteristics.

Table 2. Demographic Characteristics of US Astronauts With and Without Onycholysis Injury

Characteristic	Onycholysis injury (N=22 crewmembers)		No onycholysis injury (N=157 crewmembers)	
Men	18		124	
Women	4		33	
Right Handedness	16		135	
Left Handedness	2		26	
	Onycholysis (N=31 events)		No onycholysis injury (N=11,995 events)	
Extravehicular activity training event	27		11,677	
Extravehicular activity spaceflight event	4		318	
Phase VI glove type	29		5,451	
Series 4000 glove type	2		5,760	
	Mean	Standard Deviation	Mean	Standard Deviation
Age (years)	44.2	± 3.8	42.5	± 5.3
Duration of event (minutes)	355.6	± 53.9	271.7	± 98.6

Delta of glove size and anthropometry middle- finger length (in/cm)	in: 0.096 (cm: 0.244)	± 0.138 (± 0.351)	in: 0.063 (cm: 0.160)	± 0.193 (± 0.490)
Delta of glove size and anthropometry hand circumference (in/cm)	in: 1.138 (cm: 2.891)	± 0.576 (± 1.463)	in: 0.767 (cm: 1.948)	± 0.597 (± 1.516)

Onycholysis Predictive Analysis

Likelihood of onycholysis injury was related to several potential risk variables. Table 3 displays the full logistic regression model showing how the independent exposure variables related to injury. When including all variables, only glove model, the delta for glove size and middle finger-length, and training 2002-2004 remained in the final model (significant at $p \leq 0.15$).

Table 3. Parameter Estimates for Onycholysis Injury Full Model

All potential independent exposure variables included; CI=95% confidence interval; * Represents significance at the $p \leq 0.15$ level					
Parameter	Parameter estimate	Standard error	p-value	Odds ratio	95% CI
Intercept	-13.247	2.186	<0.001		
Sex	0.841	1.047	0.422	2.318	0.298-18.045
Age	0.063	0.046	0.174	1.065	0.973-1.166
Handedness	0.510	0.691	0.460	1.666	0.430-6.448
Anthropometric principal component	-0.002	0.116	0.986	0.998	0.796-1.252
Glove model	1.921	1.226	0.117*	6.827	0.618-75.444
Duration of training/spaceflight event (hours)	0.449	0.309	0.146*	1.567	0.855-2.871
Number of training/spaceflight events in past month	-0.112	0.117	0.336	0.894	0.712-1.123
Delta of glove size and anthropometry for middle-finger length	2.065	1.018	0.043*	7.789	1.073-58.001
Delta of glove size and anthropometry for hand circumference	0.352	0.598	0.556	1.422	0.440-4.596
Training or spaceflight	0.966	0.620	0.119	2.627	0.780-8.852
Training 2002-2004	1.273	0.392	0.001*	3.573	1.658-7.699

The full model was made parsimonious by iterating the models with a backwards, stepwise approach to remove the variables with the least statistical significance. Independent exposure variables retained in the model at the $p \leq 0.15$ level included sex, age, glove model, duration of the event (hours), the delta for glove size and middle-finger length, training versus spaceflight, and training 2002-2004. Table 4 displays the parameter estimates, odds ratios, and confidence intervals for each of the variables retained in the model.

Women had 2.62 times greater odds of reporting an onycholysis injury than men. The odds of reporting this injury were 6.5 times greater for every year of increase in age. For every hour of increase in event duration, there was a 57% increase in the odds of reporting injury. For every one inch of difference (delta) between glove size and anthropometry there was a nearly 8 times greater risk of reporting an onycholysis injury. The odds of reporting onycholysis injury were 8.5 times greater when crewmembers were wearing Phase VI gloves than when they were wearing Series 4000 gloves.

The two control variables, training versus spaceflight and training between 2002 and 2004, were both significant as would be expected. More injuries were reported during training than during spaceflight and more injuries were reported during the years 2002 – 2004 than in other years.

Handedness, anthropometric principal component, and the number of events in the past month were not significantly related to an increased risk of reporting an onycholysis injury.

Table 4. Parameter Estimates for Onycholysis Injury Parsimonious Model

CI=95% confidence interval; * Represents significance at the $p \leq 0.15$ level					
Parameter	Parameter estimate	Standard error	p-value	Odds ratio	95% CI
Intercept	-13.194	2.365	<0.001		
Sex	0.964	0.493	0.051*	2.622	0.997-6.894
Age	0.063	0.042	0.131*	1.065	0.981-1.156
Glove model	2.144	1.114	0.054*	8.535	0.961-75.811
Duration of training/spaceflight event (hours)	0.451	0.309	0.144*	1.570	0.857-2.875
Delta: Glove size and anthropometry for middle finger length	2.042	1.191	0.087*	7.709	0.746-79.623
Training or spaceflight?	0.928	0.611	0.129*	2.529	0.763-8.381
Training 2002-2004	1.272	0.398	0.001*	3.566	1.633-7.786

Using the risk variables noted above and combining them with the two control variables (spaceflight versus training event and 2002-2004 time period), a preliminary risk prediction model can be formulated for onycholysis injuries (below). The results of this calculation are based on a 100-point scale of likely occurrence.

$$\log\left(\frac{p}{1-p}\right) = -13.19 + (0.96 \times \text{sex}) + (0.06 \times \text{age}) + (2.14 \times \text{glove model}) + (0.45 \times \text{event duration}) + (2.04 \times \text{middle finger delta}) + (0.93 \times \text{event type}) + (1.27 \times \text{injury during 2002 – 2004})$$

Where sex is male (0) or female (1), age is an integer or decimal value in years, glove model equals Series 4000 (0) or Phase VI (1), event duration is an integer or decimal value in hours, middle finger delta is an integer or decimal value in inches, event type is EVA training (0) or EVA spaceflight (1), and during 2002-2004 is True (1) or False (0).

Discussion

Onycholysis in the NASA Astronaut Population

Fingernail issues affecting astronauts have been documented since the Apollo program (1961 - 1972), when crews had issues with subungual hematomas and lifting fingernails. As Apollo astronaut Harrison Schmitt related in an interview in 2000, “no matter how closely you cut your fingernails, every time you reach for something or moved in that glove, you would tend to scrape your nail against the bladder of the suit, the rubber bladder. I even wore liners, nylon liners, to reduce that, but still you would do that, and you'd gradually lift the nail off the quick” (Schmitt, 2000). Crew fingernail onycholysis is reported as a continuing issue in several reports on EVA spaceflight injuries (Strauss, et al., 2005; Viegas, et al., 2004), and in reports from researchers who attempted to better understand (Opperman et al., 2010) and mitigate (Jones, et al., 2008) the problem.

Onycholysis in Surrogate Populations

“Onycholysis is frequent in bartenders, cannery workers, dishwashers, cosmetologists (including barbers), janitors, machinists, carpenters, jewelers, weavers, electroplaters, and plastic workers among others” (Adams, 1985). It has also been reported in ballet dancers (Shah, 2010), dentists (Mosannen-Mozafari, et al., 2011), slaughterhouse workers (Baran, et al., 2012; Moore & Garge, 1997), athletes (Baran & Badillet, 1982), housewives (Sharquie, et al., 2005), and people who use personal digital assistants excessively (Olszewska, et al., 2009). Evaluation of these populations revealed no candidate surrogate population with an etiology of onycholysis clearly related to spacesuit exposure.

Causes of onycholysis are widely variable and many are not relevant to the astronaut population. The possible causes and their relevance to the astronaut population are outlined in Table 5. The likelihood that the possible mechanism was relevant to the astronaut population was given a subjective rating of high, possible, or unlikely by investigators.

Table 5. Onycholysis Causes in the General Population and Their Possible Relationship to an Astronaut Population

Possible cause	Relevance to astronauts
Repetitive trauma (Baran & Badillet, 1982; Samman, 1979) including:	High
• Scraping, cropping, and separating activities (Adams, 1985)	
• Pulling off artificial fingernails (Calnan & Sarkany, 1958)	
• Prying open walnut shells (Cohen, et al., 1975; Wilkinson, 1985)	
• Plucking strings (musicians) (Cohen, 2008)	
• Contact with shoes, poorly fitting shoes (Burkhart, 1999; Shah, 2010)	
• Skinning or removing fat from animals (Baran, et al., 2012; Moore & Garge, 1997)	
Moisture exposure (Adams, 1985; Sharquie, et al., 2005)	Possible

Pressure on finger pads (Mosannen-Mozafari, 2011)	Possible
Blood flow impingement (Cabanillas, et al., 2011)	Possible
Phototoxic reaction to medication use (Beers, 2006)	Unlikely
Infection (Beers, 2006; Mosby, Inc, 2009)	Unlikely
Allergic reaction to nail care products (Baran & Kechijian, 2000; Barnett & Scher, 1992; Food & Drug Administration, 2020)	Unlikely
Foreign bodies under nails (Adams, 1985)	Unlikely
Dermatitis (Mosby, Inc, 2009)	Unlikely
Psoriasis (Mosby, Inc, 2009; Sehgal, et al., 2011; Tosti, et al., 2009)	Unlikely
Thyroid disorders (Ghayee, Matten, & Cooper, 2005)	Unlikely
Onychomycosis (Baran & Badillet, 1982; Sharquie, et al., 2005)	Unlikely

Several different types of risk variables for onycholysis were considered on the basis of the literature review. These considerations drove the development of candidate variables specific to spacesuit-related onycholysis, which were then mined from various NASA data sources. Candidate variables that had sufficient datasets were then included in multiple logistic regression analyses. Risk of onycholysis injury was found to be related to duration of the event, type of glove model, delta between finger length and glove length for the middle finger, sex, and age.

Women had greater odds of reporting an onycholysis injury than men. Evidence from dermatology literature indicates that onycholysis may occur more often in women than men, but for reasons attributable to exposure to nail cosmetics and strong soaps and overaggressive care of the nails (Daniel, et al., 2011).

This analysis also found that the odds of reporting an onycholysis injury were greater for every year increase in age. This may be because onycholysis injuries occur slowly over many training events; thus reporting may occur later in training and later in age.

The odds of reporting onycholysis were greater for every inch (2.54 cm) increase in the delta between glove size and the anthropometry of middle-finger length, although actual differences were often much less than an inch. This may be counterintuitive due to the fact that onycholysis injuries have been theorized to be caused by mechanical stressors from the glove on the fingernail and/or fingertip, which would suggest that a tighter glove is more likely to contribute to injury. This analysis seems to indicate increased risk of onycholysis as the glove finger gets farther from the finger itself or that poor glove fit itself may be an issue. One speculation related to this finding is that when more bladder and restraint layer material has to retract back to the fingertip, this excess material could create folds or creases that might create pressure points that push into the fingernails as the hand is being used.

Although this study controlled for enhanced injury reporting during the 2002-2004 timeframe, the possibility exists that a mindset shift resulted in more reliable reporting and/or injury data records after 2004. Strauss (2004) reports that the increased rate of complaints recognized in early 2002, which led to the suit symptom study, may have previously gone unreported or not fully captured in the medical records. This indicates that astronaut EVA injury records before 2002 are suspect. While this reporting bias has the potential to affect all results, it most significantly affects the glove model risk prediction.

The odds of reporting any injury increased significantly when crewmembers used a Phase VI glove instead of a Series 4000 glove. However, several confounding factors might account for these results. Although the enhanced reporting period 2002-2004 was controlled for in the analysis, comparison of

injury data from after this period with data from before this period indicates that crewmembers may have become more comfortable with reporting injuries and continued doing so, even after the 2002-2004 study was completed. As the Series 4000 glove was primarily used before 2002 and the Phase VI glove was dominant during the 2002-2004 period and after, an increase in reporting of injuries could account for the results indicating the Phase VI to be more injurious than the Series 4000 glove. As data were replaced for nearly 30% of glove types, misattribution to a particular glove type may have also occurred. This was likely not the case as most of the glove replacements were for during time periods when one glove model was used exclusively. If the data were misattributed, the effect for one glove type could be enhanced or diluted. Further, the implementation of the Phase VI glove resulted in a reduction of the liquid cooling ventilation garment vent tube length from the wrist to the upper arm. Not having the vent tubing in the glove region has been theorized as a potential contributor to injury due to increased levels of humidity in the glove cavity (Jones, et al., 2008). Lastly, it is possible that a unique design feature and/or sizing methodology employed with the Phase VI glove makes it inherently more injurious during use than the Series 4000 glove.

In the current study, anthropometry was not related to injury, which directly contradicted previous reports that increased hand circumference was related to increased risk of onycholysis (Opperman et al., 2010). This analysis included a more comprehensive set of other contributing factors, whereas the analysis by Opperman (2010) used solely anthropometric hand measurements as predictors of onycholysis, other than one specific analysis that also included body mass index. When the anthropometric principal component variable was replaced with the more specific hand circumference of the dominant hand in the model, it was found there was no relationship ($OR=1.386$, $p = 0.611$) between hand circumference and onycholysis injuries.

Conclusion

While the risk association tables and mathematical model noted in Results and Discussion sections above can be considered guidelines, they should be considered as preliminary findings toward mitigating onycholysis. Unfortunately, because of investigation constraints, investigators were only able to attain complete sets of only some (not all) candidate variables or simplified versions of other variables, limiting the ability to evaluate injury thresholds. For example, results of this study indicated that with respect to onycholysis, the duration of the event, the type of glove used, the difference (delta) between the finger and the tip of the glove, sex, and age all mattered, but a distinct threshold of concern cutoff for where onycholysis was not observed or was not obtained. Retrospective analysis for the years 2010 through 2020 could be conducted in order to validate this preliminary model. Phase VI gloves were the only glove model used during this alternative timeline and injury mechanisms and the magnitude of injuries could be further elucidated. In addition to retrospective analysis, prospective efforts could be made to both validate the preliminary model from this study, and further, quantify and understand the environmental characteristics of the suit-body relationship within the EVA glove. This information could directly be tied to the risk variables, gathered from literature, that pertain to metrics acting against the hand and nails such as forces, moisture, or temperature, and how they are related to the task-related variables of task type, duration of exposure, and frequency of exposure. Association with injury recurrence (chronic) and cumulative risks should also be pursued if data are available. Ultimately, understanding the mechanisms of these injuries and how to avoid them should aid in the design of future gloves and the formulation of operational guidelines for EVA training and spaceflight exposure that minimize or eliminate the potential for crewmember pain and injuries.

Key Points

- Multiple logistics regression was utilized to develop a mathematical model for estimating the amount of risk that astronauts would encounter for developing onycholysis fingernail injuries

- Risk factors that were calculated as important to capture included the duration of the EVA event, the type of EVA glove used, the distance delta between the fingertip and the inside edge of the glove, astronaut sex, as well as age
- Additional work-related risks to consider quantifying and monitoring based on literature, include forces acting on the fingers and nails, moisture of the nails, ambient temperature near the nails , type of work activity, duration of work activity, and frequency of exposure to these environments
- In addition to designing out risk for next generation gloves, currently utilized Phase VI glove risk should utilize administrative controls such as improved glove sizing techniques, reducing exposure time during ground based training in neutral buoyancy pool training, and improving data collection standards for type of metrics collected and consistency of collection

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