

diving

INTO O&P RESEARCH

The University of Hartford takes to the water to study prosthetic use and optimization among wounded warriors



NEED TO KNOW

- The University of Hartford Department of Rehabilitation Sciences has partnered with the Combat Wounded Veteran Challenge (CWVC) in carrying out a research project centered around studying amputees' performance with and without their prostheses in an underwater scuba-diving setting.
- Each year, veterans and wounded service members with amputations take part in a week-long CWVC Scuba Challenge below the coast of Looe Key, Florida; for the past three years, researchers Duffy Felmlee, MSPO, CPO, and Michael McCauley, MSPO, CPO, have joined the dives.
- The research methodology relies on an array of inertial sensors and video recording, which allow the researchers to evaluate kinematic data in real time during the data collection and also review the data more thoroughly, with the assistance of other University of Hartford researchers, in the lab.
- Working with the wounded warrior population in an underwater setting poses some challenges, such as ensuring electronic sensors are not damaged in the water, assisting participants in achieving neutral buoyancy while using their prosthesis, and communicating with subjects while submerged.
- To date, CWVC and University of Hartford have seen “overwhelming positive results” and are finding that most divers prefer to wear their prostheses while diving. The team plans to increase the sample size in the coming year; they hope to triple the trials in 2019.
- The ultimate goal of the research is to be able to recommend best practices related to suspension, knee, foot/ankle, and fin combinations—information that prosthetists could share when assisting patients who want to participate in scuba.



A researcher adjusts a wrist-mounted heart rate monitor on a combat wounded veteran in the test environment.



TODAY'S O&P ACADEMICIANS AND

clinicians are taking research to new heights, investigating many aspects of orthotic and prosthetic intervention to determine the efficacy of various devices and treatment protocols. But researchers at the University of Hartford have taken their research to new *depths*—to the bottom of the sea.

Scuba diving can be challenging for amputees—but it's an activity that can serve both recreational and rehabilitative purposes. For the past several years, veterans and wounded service members with amputations have taken part in an annual week-long Scuba Challenge, hosted by the Combat Wounded Veteran Challenge (CWVC). Participants learn to improve their diving skills, with or without their prostheses, and spend time “giving back” by planting corals along Florida's decaying barrier reef.

Three years ago, the University of Hartford was invited to partner with CWVC and conduct research during the annual Scuba Challenge. “CWVC was in search of an institutional partner to help them complete one of its mission objectives of ‘research and innovations in field-based assessments/treatment of orthotics and prosthetics,’” explains Duffy Felmlee, MSPO, CPO, assistant professor in the university's Department of Rehabilitation Sciences. In response, Felmlee became one member of a team of researchers—which also includes Michael McCauley, MSPO, CPO; Kristamarie Pratt, PhD, MEng; and Matthew Parente, MS, PT, CPO, FAAOP—that has been formulating innovative field protocols and data analysis “for the immediate and future benefit of combat wounded veterans,” says Felmlee.

A Giant Stride

The CWVC's annual Scuba Challenge, which takes place below the coast of Looe Key, Florida, is an ideal setting for the University of Hartford team to conduct investigations regarding underwater swimming in amputee subjects. The challenge is “the flagship event for CWVC, as it combines all of the major tenets of the organization into a high-impact, seven-day event” that offers camaraderie, research, and community, says Felmlee. Participants also benefit from instruction provided by Scubanauts International, an organization that trains junior scuba divers to participate in the sport and offers information about oceanographic preservation and research.



Researcher Michael McCauley, MSPO, CPO, adjusts a buoyancy control mechanism on a transfemoral swim prosthesis.



A researcher evaluates the functionality of a knee unit while combined with a buoyancy control mechanism in open water trials.

Wounded Veterans Benefit From UNDERSEA ADVENTURES

THE COMBAT WOUNDED VETERAN Challenge (CWVC) sets itself apart from other organizations developed to improve the lives of wounded or injured veterans by including a research directive in its mission. Participants with amputations, post-traumatic stress, and traumatic brain injury can turn to a variety of organizations to take part in athletic activities, but, with the added research component, participants “feel a connection to something greater—to make life better not just for themselves, but for others” who may experience similar injuries, explains Captain Dominic Gorie, a retired Naval aviator and astronaut and a director on the CWVC Board of Directors.

CWVC offers physically and psychologically demanding extreme outdoor events throughout the year, which have included activities such as hiking, mountaineering, and sailing, but the annual week-long Scuba Challenge has become the organization’s most successful challenge, says Gorie. “We invite families to take part so the participants can have a whole family experience.” After getting away from their everyday routines in a relaxed beach setting accompanied by spouses or children, participants go home in a much better frame of mind, according to Gorie. “Wounded veterans have emotional and mental



Captain Dominic Gorie

scars” that can be alleviated, to an extent, by scuba diving with other wounded veterans and their families—while also participating in reef restoration and working with University of Hartford researchers in discovering better ways of propulsion.

Participants spend the first couple of days being fit for gear and being evaluated to ensure everyone is fully prepared for diving. They spend rest of the trip diving two or three times daily, sometimes going as far as 100 feet underwater. They devote part of their diving time to planting corals to help rebuild the reef near the Looe Key Sanctuary Preservation Area in

Florida, in conjunction with Mote Marine Laboratory and Scubans International. Last summer, they helped plant 300 coral fragments.

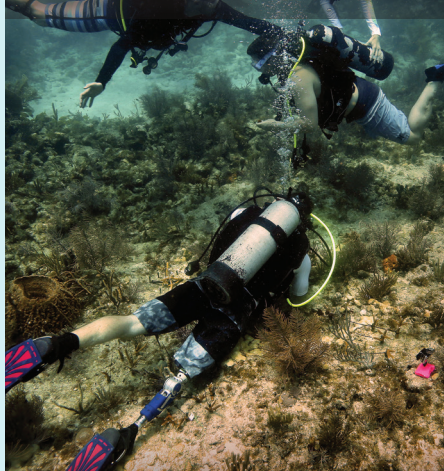
The University of Hartford research team studying amputees in the underwater environment dives alongside the veterans, many of whom have been fit with electronic sensors to collect kinematic data for their investigation. They also observe the amputees as they take part in the coral reef planting event. “From the researchers’ perspective, we value the opportunity to observe the veterans using or not using the prostheses in real-world environments,” says Duffy Felmlee, MSPO, CPO, assistant professor in the Department of Rehabilitation Sciences. “As the users focus on tasks unrelated to swimming, we are able to make note of how the prosthesis or residuum is used to assist in remaining in a stationary position, which is not easy in the best open water conditions.”

Scuba diving is “a perfect activity for veterans with missing limbs,” explains Gorie. Both unilateral and bilateral amputees have taken part in the challenge. “In a couple of cases, veterans with no limbs below the hips” have participated, he says. These individuals have tried a mega-fin, or mermaid fin, as a means of propulsion, with the researchers studying how best to help both bilateral lower-limb amputees and individuals with muscular dystrophy or lower-extremity paralysis navigate the water.

“When veterans realize they are part of this much larger goal [to design better underwater prostheses for both amputees and individuals with other health-care challenges], it excites them and opens them up to the awareness that life is not as limiting as they thought,” says Gorie. “And that’s our goal. These veterans sacrificed for our country, and we owe them, to try to return them to a fully functioning body and mind.”

Concludes Gorie: “When you combine a challenging adventure with a research component, it re-energizes the wounded vets and makes it all worthwhile.”

Combat wounded divers, prosthetic researchers, and aquatic environment researchers participate in coral restoration projects to restore damaged sections of coastal Florida.



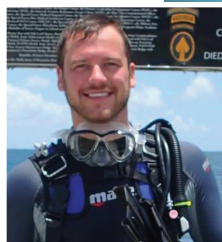
Conducting research in the underwater setting allows for data collection that will improve the design of underwater prostheses and aid individuals with limb loss in their recreational pursuits. “It is in the interest of amputee advocacy to promote activities that encourage equality with minimal accommodations to participate,” explains Parente. “Scuba can be very physically equalizing due to buoyancy and the team approach required to participate in the sport safely. As divers are trained, it is most apparent that the primary means of propulsion is achieved through symmetrical strokes of bilateral lower extremities.” But lower-extremity amputees have a disadvantage to symmetrical stroke length or limb leverage, depending on the “sidedness and level of the amputation,” says Parente.

The initial goal for the project was to establish a methodology to evaluate underwater swimming with lower-extremity amputation. “We have been able to develop a method [that] relies on an array of inertial sensors and video recording, which allows the researchers to evaluate kinematic data in real time during the data collection and also be able to review the data more thoroughly in the lab,” explains McCauley.

With more data collected each year, the team’s methods have become repeatable. “We are able to vary the components, knees, ankles, and fins (split versus solid) and compare what elements help to normalize the propulsion patterns of our amputee divers compared to our controls,” McCauley adds. “Eventually, we would like to be able to recommend best practices related to suspension, knee, foot/ankle, and fin combinations, which prosthetists would be able to recommend to patients that want to participate in scuba.”

Waves of Data

The annual nature of the Scuba Challenge makes it easy for the research team to collect data in an organized



Michael McCauley, MSPO, CPO



Left, A researcher adjusts the position of a swim foot prior to starting a round of testing environmental trials.

Below, Duffy Felmlee, MSPO, CPO, and Michael McCauley, MSPO, CPO, adjust inertial sensors prior to a swim trial in the test environment.



manner: The researchers have completed three testing phases over the past three years. “Combined, we have now tested greater than 22 subjects, unilateral transtibial and transfemoral,” as well as bilateral amputees, says Felmlee. He and his team collect heart rate data using Polar Heart Rate monitors and Polar watches; they also use APDM inertial sensors to collect segmental kinematic data.

“Our subjects have a sensor placed on each tibia, femur, and one on the lumbar spine as well the level of the xiphoid,” Felmlee explains. The sensors record the angular acceleration of each segment, which is then compared to the various trials of swimming with and without a prosthesis. “The field observations give us the opportunity to see what the manifestations of the

kinematic data quantifies,” he says. For example, one of the experienced divers who is a unilateral transfemoral amputee uses both lower extremities with a fairly symmetrical kick while using his prosthesis, but when the prosthesis is removed, “his swimming pattern moves to a porpoise style of propulsion, which requires a significant amount of trunk flexion and extension,” Felmlee says. “We are also able to observe in the pool and open water that a majority of the uninvolved limbs internally rotate—as we see with our controls—but the prosthesis will maintain a very linear motion in the sagittal plane; it is expected that this reduction in internal rotation is reducing the directional propulsion and requires our subject to compensate with the upper extremities.”



The research is far from complete, but preliminary findings suggest prostheses are helpful to scuba divers with limb loss. “Debriefing questions have provided us the feedback that divers who have acclimated to the use of their swim prosthesis feel more balance and [are more] efficient when using their prosthesis compared to without and prefer to use [their prostheses] in every dive,” says Felmlee. Divers who are newly certified have tended to not use their prosthesis on the initial dives due to the additional equipment—“divers have a significant amount of gear to keep track of and know the proper function, [and] at times the prosthesis can seem cumbersome,” he explains. “But, once the diver has become accustomed to the dive gear and is placed in a controlled environment, such as a research pool, and allowed to compare the two trials of with and without prosthesis, the [general consensus] is the use of the prosthesis requires less effort to maintain a straight course or direction.”

High and Lows

The researchers enjoy being able to conduct O&P investigations in such a unique setting, especially knowing that their work has real-life implications

to improve recreational and therapeutic activities for both wounded veterans and civilian amputees who may enjoy scuba diving. “Our current subject pool is an impressive group of combat wounded veterans,” says Felmlee. “Our intention is that the research gathered here would be able to advance the current state for activity-specific componentry to allow veterans with limb loss to participate in an activity [that] has significant physical, psychological, and social effects.”

To lead this research project, both Felmlee and McCauley had to become divers themselves. “When I learned of CWVC looking to do some scuba expeditions and they asked me to join, I thought, ‘Wow, how many prosthetists are scuba certified and have the desire to get into underwater prosthetic research? Probably not very many!’ So I jumped on it and completed all my scuba requirements as soon as I could prior to my first trip down to Key West,” recalls McCauley, who calls the experience “a dream come true.” Felmlee similarly completed scuba certification for the sole purpose of helping lead the investigations.



**Duffy Felmlee,
MSPO, CPO**

Travelling to Florida provides a welcome change of pace from the researchers’ day-to-day activities at the university. “This field collection is different than most data collection trials in the sense of getting to meet and work alongside subjects over an extended

period of time,” says McCauley. “These individuals become a motivation to do more for the community and assist in improving the quality of life for others.”

While they enjoy conducting their research, the team also is faced with challenges in the underwater setting. “Most electronics are not intended for use in the aquatic environment, so we have had to ensure that our sensors are able to withstand the demands of data collection and also be sure they are not damaged due to moisture,” explains Felmlee. This involves additional care, with researchers carefully removing the sensors from their protective sleeves and docking them for data transfer after the dives have concluded.

The reduction in gravity also can be difficult to adjust to, and some subjects experience issues regarding

orientation. “Neutral buoyancy is the goal of the diver, and this alone can be quite challenging to achieve due to some of the negative or positive buoyancy within the prosthesis,” Felmlee adds.

In addition, communication while diving can be difficult. “Although hand signals are rehearsed top side, there is inevitably a task that will provide some additional communication between researcher and subject,” says Felmlee. “What would be an easy few words may take a little extra time communicating underwater. Some may say, ‘Just go to the surface and clarify,’ which is done in some cases—but achieving neutral buoyancy can be a time-consuming task, and once that is achieved, resurfacing would be less than ideal.”

Preparing for Ascent

The university team plans to continue this research, and recently added faculty to the research team due to “the overwhelming positive results produced since the inception of this partnership,” says Parente. CWVC and the university have agreed to triple their trials in 2019.

“CWVC has seen value in the research protocol and has increased the data collection trials from a single collection period to three separate challenges [during the year]—increasing our sample sizes significantly,” says Felmlee. “Now that our methodology has given us repeatable results, we will continue to field trial various combinations of componentry to find the best combinations for different amputation levels.” The team also plans to field-test new designs, based on observations and data from previous years.

Assessing the componentry currently available, Felmlee notes that recent advances in O&P technology have led to significant improvements in allowing amputees to participate in aquatic activities—for example, with the use of noncorrosive materials and, in the case of ankles, allowing for plantarflexion when swimming. “As we look to improve upon these concepts, we have noted that allowing for a certain amount of motion at the knee

SFC Billy Costello, U.S. Army (Retired), participates in open water field testing of prosthetic swim componentry.



and ankle on the recovery stroke of a kick would be beneficial to the diver,” he notes. “Current locked components generate a power-propulsive stroke in both flexion and extension of the hip. This can lead to fatigue on the amputated side as well as asymmetrical propulsion, which requires the trunk and upper extremities to compensate.”

Recommendations and analyses such as these should assist Felmlee and his team—and O&P professionals with patients who might enjoy scuba—in promoting the sport among active amputees. “The weightless environment of submerged swimming can be an equalizing factor for all. Although scuba can be physically demanding at times, there is the ability to perform the tasks in which the individual’s technique has a greater impact on the

result than that of physical ability with or without a prosthesis,” Felmlee says. “There are studies that show improved pulmonary function with the use of compressed air, commentaries that report on the improved socialization effect of swimming with a ‘dive buddy,’ and reports that encourage the use of aquatic therapy—these are all benefits that can be obtained by the interested individual.”

“Research is not usually associated with having fun,” adds McCauley, “but working with these combat wounded men and women has not only been an honor but an absolute blast.” **CP**

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