Open Exo Safety Document

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# Purpose

The purpose of this document is to outline safety recommendations and hazard mitigation strategies for the operation and maintenance of OpenExo and its configurations to ensure the safety of users and bystanders.

# General Safety Recommendations

* Never operate or work on an OpenExo device without someone else present.
* Wear eye protection when working on or inspecting the device closely while it is powered on.
* Never touch a printed circuit board while a battery is plugged in.
* Never leave a battery plugged in when not in use.
* Assume the device’s motors will activate when powered on and take necessary precautions.
* Always inspect the device for loose connections, worn parts, and other signs of damage before use.
* Train all operators in the safe use of the device.

# Electrical Hazards

## Electrical Shock

Serious electrical shock is a hazard for any battery used to power OpenExo (e.g., 6S LiPo). These batteries can also cause burns to the skin or even death if mishandled. Ensure that no bare wires are exposed and that the PCB is enclosed to prevent electrical shock. Never touch two ends of a battery terminal, lead, or PCB with two hands, which could result in current passing through and stopping your heart.

Always handle batteries and electrical components with dry hands.

Ensure the battery or any other source of electrical power is not connected to the device when servicing.

## Fire

Improper care for the battery can lead to a fire. If the battery shows any of the following signs, dispose of it in a safe manner and do not use it any further:

* Swelling or bulging
* Leaking
* Cracks, dents, or punctures
* Overheating

Furthermore, shorting the terminals of the battery can cause the battery to heat rapidly, leading to thermal runaway and a fire. Ensure that wires directly connected to the battery are properly insulated and there is no possibility of a short circuit. Always charge batteries in a fireproof container using an appropriate charger and never leave batteries unattended during charging.

# Temperature Hazards

## Heat

The motors used on the exoskeleton have a rated operating temperature of up to 100 °C. These temperatures well exceed the recommendations of the American Society for Testing and Materials’ temperature safety recommendations (C 1055-99), which states that five seconds of contact with temperatures over 60 °C may lead to epidermal injury. We advise avoiding prolonged contact with the exposed surface of the motors and suggest utilizing designed heat shieldings for all OpenExo configurations to reduce the chance of injury in instances of accidental prolonged contact.

# Physical Hazards

## Tripping and Falling

As with any experimental device, there are potential risks related to device modification (e.g., alteration to hardware components such as sensors, alterations to software such as controllers). Following alteration or prolonged usage (where sensor wear and failure may be more common), we recommend operating the device with caution upon startup as it may behave in unexpected manners that could lead to adverse events such as trips or falls.

It is highly recommended that safety harnesses are worn during operation when possible, particularly when in use on equipment like treadmills or stair steppers.

## Cuts/Scrapes/Splinters

There are a few possible sources of cuts, scrapes, and splinters on the exoskeleton.

* The screws facing outward on the thermoformed motor mounts should be fitted with the rubber caps indicated in the assembly guide to avoid scratches.
* If zip ties are used to fasten wires in place, the burs leftover should be trimmed and filed down to avoid cuts and scrapes.
* Any sharp points or corners left over from the fabrication process should be ground down to again avoid cuts and scrapes.
* The carbon fiber uprights used to deliver the torque from the motors to the users legs should be kept in good condition and checked for any burrs, cracks, or splinters to avoid injury to the user.
* When utilizing the bodwen-transmission system there is a risk that the steel cables within the bowden tubes may snap under high loads or after prolonged usage (due to wear and tear). Generally these instances will not result in user harm as the surrounding hardware/bowden tubes usually absorb the loads. There is a possibility that cuts or other sources of injury could occur in these scenarios (although across years of bowden-transmission usage we have never had an injury). We recommend performing frequent maintenance on bowden-cable based configurations and exercising caution when applying high torques (25+ Nm). We recommend using thicker steel cables (see recommendation in “Bowden Transmission” section) when expecting prolonged periods of high torque application. In instances where the steel cables do snap, remain calm and turn off the power to the system as early as possible.

## Pinch

The moving parts of the exoskeleton can cause pinches if care is not taken. For the hip configuration, users should never place their hands between the motors and uprights during use. For bowden cable configurations, users should never place fingers inside the cartridge or between the bowden cables. Moreover, users should avoid placing their hands between the hinges connecting the motors to the belt. In general, users should be aware of which parts of the exoskeleton articulate and keep appendages away from those areas.

## Blunt Force

The uprights attached to the motors can pose a significant risk if not securely fastened during operation. Due to their lightweight design, the motors can cause the uprights to spin rapidly if left unsecured (e.g., not attached to the thigh or calf via cuffs). To prevent injury, ensure the uprights are firmly attached to the user’s legs and never operate the exoskeleton if the uprights are unrestrained.