The design and preliminary characterization of an active back-support exoskeleton

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INTRODUCTION

A significant portion of the civilian workforce performs physically demanding jobs that involve repetitive bending down, lifting, and carrying heavy objects. One such industry is construction, where a survey indicated that 16.5% of workers experienced lower-back musculoskeletal symptoms [1], with cumulative low back load identified as a major risk factor [2]. Wearable back-support exoskeletons have emerged as a potential solution for reducing risk of such injuries [3]. This study will investigate an active back support exoskeleton design that incorporates actuators to decrease to load on workers lifting heavy objects.

MATERIALS AND METHODS

A baseline active exoskeleton design was developed, and two rotary actuators were selected. The design was initially modified for adjustable sizing, comfortability, and ergonomics, then various accessories, and attachment methods were compared and selected. The exoskeleton is adjustable to cover the 15th – 85th percentile hip breadth for both men and women [4]. Material options commonly used in exoskeletons, including carbon fiber, nylon, aluminium, titanium, magnesium, and steel were assessed in terms of weight, strength, manufacturability, and cost [5]. Final material selections were made for each component. To further reduce weight, topology optimization and finite element analysis (FEA) were conducted in ANSYS using 10-node tetrahedral solid elements (SOLID187) with orthotropic and isotropic material models.

RESULTS AND DISCUSSION

The selected Maxon High Efficiency Joint actuators each weigh 1.96 kg and deliver a maximum torque of 60 Nm, providing in total about two-thirds of the hip torque typically required during a semi-squat [6, 7]. Polyurethane foam padding, adjustable straps, and a wheelchair chest support were selected to improve user comfort and minimize adverse effects from high torque loads. Most structural components are manufactured using fused deposition modelling of Nylon 12-CF, a composite consisting of a nylon 12 matrix reinforced with 35% chopped carbon fiber by weight. This material offers a key advantage over alternatives by combining low density, high strength, and the ability to fabricate complex geometries via additive manufacturing. An aluminium version of the exoskeleton is planned for future investigation, as it may provide a lighter and more cost-effective option for commercial use. After multiple iterations of topology optimization and FEA, the final back-support exoskeleton (Fig 1) has a total weight of 8.49 kg with a yield strength safety factor of 1.4 when 60 Nm is applied to each side. The performance of Nylon 12-CF and aluminium 6061 for the topology-optimized back section are compared (Table 1).

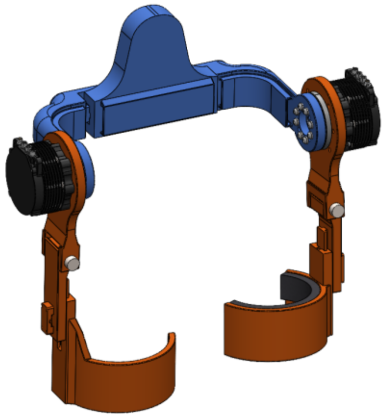

Fig 1 CAD model of the active back support exoskeleton

CONCLUSION

The final design of the exoskeleton is a topologically optimized structure that prioritizes user safety and comfort and can be adjusted to accommodate a range of anthropometries. By providing controllable supporting torques of up to 60 Nm per actuator, the exoskeleton has the potential to reduce lower-back loading which could in turn help lower the risk of related injuries. Empirical validation is needed to confirm this effect.

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Table 1: Nylon 12 CF and Aluminium 6061 material comparison for topology optimized back section. [8, 9].

	Nylon 12 CF	Aluminium 6061
Density (kg/m^3)	1150	2700
Tensile Yield Strength (MPa)	34 to 76	276
Tensile Modulus of Elasticity (GPa)	2.3 to 7.6	68.9
Optimized Back Section Weight (kg)	2.55	2.14