In this study, we introduced a biarticular configuration of an exoskeleton assisting hip and knee joints, delivering torque to the knee joint distally. We modeled the proposed exoskeleton through a musculoskeletal simulator framework and compared it to a typical monoarticular device that assists each joint directly by mounting an actuator to the joint. Modeling these exoskeletons through the musculoskeletal simulator framework provide us insight into not only the moment and power profiles of exoskeletons and their power consumption, but also the effect of these assistive devices on the muscle activity, power expenditure, and joint reaction forces and moments of the simulated subjects.\\

At the first stage of this investigation, the simulation-based study was conducted with ideal exoskeletons in which devices had no mass, inertia, or any limiting factor, and the actuators of these devices had no constraints on delivering torque to the joints. This type of simulations was employed to verify the purposed exoskeleton modeling on the musculoskeletal simulator and gain insight into the performance of these devices, and their effect on the assisted musculoskeletal models under ideal conditions.\\

This phase of the study showed that despite the same effect of both devices on the metabolic rates of subjects, the devices have different profiles and power consumptions. These simulations demonstrated that loading subjects with a heavy load mainly changes the profiles by magnitude and time-shifting, which depends on the toe-off time. It was also shown that the biarticular hip actuator has a more uniform work distribution in different load conditions, and it was less affected by loading subjects. Studying the muscular activities of the assisted subjects showed that the muscular activations of both assisted and unassisted degrees of freedom are also affected by augmenting ideal devices. Through the joint reaction loading analysis on this phase of simulations, it was observed that the assisted subjects have considerably different reaction loadings in all degrees of freedom of lower extremity, and interestingly, despite the same effect of devices on muscles and metabolic rates of assisted subjects, they have different impacts on the reaction loadings of the knee and patellofemoral joint.\\

Although studying the exoskeletons without any restriction on their performance provides handy erudition about the exoskeletons, it is necessary to analyze and compare them in more realistic conditions that can be applied in real-time applications. Consequently, we organized another stage for this study in which we introduced a novel Pareto simulations framework to conduct reliable comparisons among different configurations of the exoskeletons in their optimal configurations by taking advantage of Pareto optimization and Pareto filtering methods and implementing them into the musculoskeletal framework. This designed method can provide average optimal trade-off cases for each configuration of the assistive devices based on the defined optimization objectives, which were defined as metabolic cost reduction and device power consumption as two optimization criteria in this study. The Pareto simulations and optimal devices resulting from this method can be employed to conduct fair comparisons, and it was used to study and compare the assistive devices with constraints on their maximum torque that can be provided to the joints to the joints.\\

Through this phase of the study, we showed that in both loading conditions, configurations exist for both devices that can provide the assistance of ideal exoskeletons with lower power consumption. This finding implies that in order to conduct fair comparisons of different devices, performing Pareto simulations is inevitable. The second phase of the simulations with constrained devices revealed that although both devices have practically the same effect on the metabolic cost of subjects, the optimal configurations of these devices are considerably different and have different effects on the muscle activations of assisted subjects and the similarity between devices in ideal condition does not hold for constrained devices. Notwithstanding practically the same total metabolic rate, further analyzing and comparing the metabolic rate of each muscle showed that the effect of these devices on the trends and rates of some muscles differed throughout the optimal trade-off curve.\\

Analyzing the power consumption of optimal devices resulting from the second stage revealed that the devices have remarkably different actuator arrangements for delivering the same amount of assistance to the subjects. In the subsequent analysis of optimal devices, it was shown that both devices have considerably different moment and power profiles in comparison with each other and their ideal configurations. Additionally, it was revealed that the monoarticular exoskeleton has high variations within optimal devices and between load condition, which can considerably complicate the controlling of the device in different conditions. Studying the regeneratable power of the devices in different efficiency conditions and its effect on the overall performance of the device showed the essence and importance of designing a regeneration mechanism and battery. Through joint reaction force analysis, it was demonstrated that constraining devices affect the loading of the joints, and that they do not resemble the loading of joints assisted with ideal devices.\\

This study has been accomplished using OpenSim \cite{89}, which cannot simulate any dynamic variations without capturing their effect experimentally due to its neural control algorithm\cite{92}. To investigate the effect the inertial properties of optimal devices, obtained from the Pareto simulations, on the metabolic rate of assisted subjects, we adopted the model developed by Browning et al. \cite{45} and performed offline simulations to investigate the effect the inertial properties of optimal devices on the optimal trade-off curves of devices and assisted subjects' effort.

Additionally, we introduced a modified augmentation factor as a modification of the augmentation factor developed by Mooney et al. \cite{41} as a general exoskeleton performance metric framework. The augmentation factor was modified by combining the effect of inertia along with mass on the performance of devices, and it was used to study the efficiency of selected optimal devices obtained by Pareto simulations under consideration of their inertial properties.\\

The last stage of this study was a step in the direction of providing more realistic results from the simulations. This phase of the study revealed that the performance of devices is profoundly affected by their inertial properties; the effect was more severe for the monoarticular device due to its kinematic design. Analysis of optimal devices under the effect of their inertial properties using developed model, and the modified augmentation factor showed that most of the optimal biarticular exoskeletons were able to preserve their optimal performance under their mass and inertia effect. The ability of the biarticular devices on preserving its optimality under the effect of their inertial properties eases designing an optimal device. Unlike the biarticular exoskeleton, the developed model, along with the modified augmentation factor, showed that the optimality of monoarticular devices was profoundly altered by reflecting the effect of their inertial properties. To improve the performance of the monoarticular exoskeleton, we suggested two monoarticular designs different from its conventional design that can mitigate the effect of inertial properties of the device more effectively. Finally, the performance of the devices was analyzed under regeneration, revealing the promising effect of regeneration on the optimality of devices.\\