Goal: Create a piece of in-water resistance training equipment for swimmers providing variability in the resistive force applied, to allow for more personalized resistance training.

Table 1: Requirements for Personalization

Requirements for Personalization (R1):			
Requirement	***Metric***	***Evaluation Criteria***	***Justification***
R1.1 Levels of Resistance: The design shall provide at least 5 levels of resistance greater than 36.75N.	N	EC 1.1 A better design is one which can provide more than 5 distinct levels of resistance between 36.75N and the upper bound of resistive force provided.	The lower bound of resistive force provided by reference designs considered was 36.75N[5], with designs generally providing three to four discrete levels of resistance[1][2][3], with only the power tower providing a continuous range of resistances. The design should hence at a minimum be able to provide 36.75N of resistive force to be consistent with existing alternatives. Each design will have its own inherent maximum possible resistive force it can provide. Between 36.75N and this upper bound, the design should provide at least 5 intermediate resistance levels to provide greater personalization of resistance than existing alternatives. *A requirement for an upper bound resistive force was not imposed as while some designs may provide greater force than others, the need identified was a lack of variability in resistive force, rather than existing designs providing insufficient resistive force. Each design may provide unique merits which should not be immediately eliminated solely because it provides less force than an alternative.

Additional Evaluation Criteria	
EC 1.2 Difference Between Resistance Levels A better design has a smaller difference between resistance levels. (% difference)	5-10% load increments are considered optimal for progressive strength training for youth athletes [6]. This allows for increased personalization to each swimmer's unique training regime while progressing to greater levels of resistance.
EC 1.3 Duration of Continuous Resistance: A better design is one which provides continuous resistance for more than 25m (length of pool lane). (Metric: metres)	The shortest competitive event for all strokes is 50m. As the HP swim team only trains in 25m short course pools, a better design is one which allows swimmers to practice swimming the full race distance with resistance applied to better prepare them for racing conditions [7][8][9][10].
EC 1.4 Speed-Independent Resistance: A better design is one which is less dependent on the speed of the swimmer (Metric: Coefficient of Variation of the resistive force measured at three different speeds)	Having the design be less dependent on speed will give swimmers greater control over the resistance provided by the training equipment, aligning with the team's value to make the design as personalizable as possible to every swimmer. Coefficient of variation can be determined by plotting resistive force against speed, and multiplying the ratio of standard deviation to mean by 100. If CV is less than 10%, then the design is speed independent [11].
EC 1.5 Areas of Targeted Resistance A better design is one which provides targeted resistance that can only be overcome using both the arms and the legs. (Metric: yes/no)	The same design can be used for arm and leg targeted training exercises. This eliminates the need for the swim team to purchase multiple pieces of equipment for these different drills, aligning with sustainability principles.

Goal: Want a safe design that will not endanger or harm the swimmer in any way.

Table 2: Requirements for Safety

Requirements for Safety (R2):			
Requirement	***Metric***	***Evaluation Criteria***	***Justification***
R2.1 Impact on Pool Water: The water with the device shall pass the black disc test [12].	Yes/No	N/A	Poor water clarity indicates high turbidity, which reflects a high concentration of suspended particles in the water. When turbidity is high, water appears cloudy, dull, or discoloured because suspended particles scatter light and reduce visibility. [12] This requirement helps ensure that the design does not release visible materials or particulates into the pool that would degrade water clarity. One way to assess this is through a black disc test, which evaluates water clarity by measuring visibility through the water [12].
R2.2 Impact on pH: The design shall not modify the acidity of the pool outside of the range of 7.0-7.8	pH of water	N/A	The device changing the pH of the water will affect how chlorine and bromine act in the water [13], potentially reducing the neutralization of germs and bacteria.
R2.3 Resistance to Extreme Force: The design shall be able to withstand a force of 103.97 N without failure.	N	EC2.3 A better design is one which can withstand a greater amount of force without failure.	The design should be able to withstand the force of the swimmer while in use without breaking, as a broken design may injure the user or nearby swimmers. The mean force exerted by a swimmer as measured by the tethered swim test following a warmup is 103.97N. Therefore, the design shall withstand a force of 103.97N without failure [14].

Goal: Want a design that will offer variable resistance without interfering with swimmer technique, and will promote the training of the swimmer.

Table 3: Requirements for Functionality

Requirements for Functionality (R3)			
Requirement	***Metric***	***Evaluation Criteria***	***Justification***
R3.1 Effect on Range of Motion: The device shall maintain a functional clearance envelope that permits **180.8° of shoulder flexion** and a **150.0° total rotational arc** (consisting of at least 60.0° Internal and 90.0° External rotation) without mechanical interference. Additionally, it must allow a minimum of **39.0° of horizontal abduction** to mitigate injury risk [15][16][17].	(º)	EC3.1: The greater the range of motion, the better.	According to Cejudo et al. (2019), elite swimmers require these specific ROM values (Table 2) to maintain a streamlined position and execute an effective "high-elbow" catch. Restricting these motions is directly correlated with a 3.6 times higher risk of developing subacromial impingement and shoulder pain. Therefore, the device must allow for this full 3D "envelope" to ensure both hydrodynamic efficiency and injury prevention [15][16].
R3.2 Additional Attachments: The design shall provide varied levels of resistance without requiring additional attachments.* *For instance, parachutes only provide variable resistance by changing the parachute attachment that is tied to the swim harness.	Yes/No	N/A	Reducing the number of attachments will simplify the use of the design, allowing swimmers to learn how to use it faster. It will also lessen clutter near the pool edge which will reduce tripping hazards.
R3.3 Adjustability: A design that is attached to the swimmer's waist shall be adjustable to fit waist sizes ranging from between 65.5 cm to 105.9 cm [18][19]. A design that is attached to the swimmer's mid-arm shall be	Centimetres	N/A	The design must be able to fit the HP members at the Mississauga Aquatic Club, who are 14-18 years old [8]. The mean 5th percentile waist circumference for 14-year-old girls is 65.5 cm, and the mean 90th percentile waist circumference for 18-year-old men is 105.9 cm. The mean 5th percentile mid-arm

adjustable to fit mid-arm sizes ranging from between 21.9 to 40.1 cm.			circumference for 14-year-old girls is 21.9 cm, and the mean 95th percentile mid-arm circumference for 18-year-old men is 40.1 cm. Designing adjustability for this range should allow the design to be used by the majority of HP aquatic swim members. [19]
R3.4 Setup Time: The time taken to change between two resistance levels should be less than 30 seconds.	Seconds	EC3.4 A better design is one which requires less than 30 seconds to change between two resistance levels.	HP swim practices are fast paced. The training equipment should not interfere with the pacing of these practices and hence there is a need for resistance levels to be swapped quickly. The time threshold is based on the time taken for drag socks to be put on and removed with an approximated transition time of 30 seconds. [7]

Goal: Want a design that will fit into available storage space at the centre.

Table 4: Requirements for Storage

Requirements for Storage (R4)			
Requirement	***Metric***	***Evaluation Criteria***	***Justification***
R4.1 Portability The design shall fit into a 13 x 13 x 11-inch space.	Inches	EC 4.1 A better design is one which can be stored in a space smaller than 13 x 13 x 11 inches.	Current resistance training equipment is stored in a crate measuring 13 x 13 x 11 inches [7]. To maintain compatibility with current storage procedures, the design should fit within this space. A smaller design would allow for more equipment to be stored in the same crate.

Goal: Want a design that can endure the pool environment and specifically immersion in water.

Table 5: Requirements for Durability

Requirements for Durability (R5)			
Requirement	***Metric***	***Evaluation Criteria***	***Justification***
R5.1 Use Cycles: The design shall withstand 18400 use cycles without failure.	Use cycles until failure	EC 5.1 A better design can withstand more than 18400 use cycles without failure.	ISO 20957-1:2024 requires equipment to maintain safe performance under repeated use conditions representative of commercial environments. Based on training practices, a design is expected to last two years, corresponding to 18400 use cycles (46 weeks, 200 uses per week), it ensures equipment remains functional for a similar amount of time as existing equipment [7].
R5.2 Withstanding Chlorine: The design shall contain material(s) with a breaking force retention of 100% with chlorine exposure in accordance with ISO-17608.	Yes/No	N/A	Equipment located in aquatic facilities are exposed to chloramines, chlorinated water, high humidity, which accelerate corrosion in metallic and inorganic material [20]. To ensure long-term structural integrity, material selection shall maintain strength following chlorine exposure as specified in ISO-17608 [21].