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PRODUCTS AND DEVICES

A novel portable and cost-efficient wheelchair training roller for persons with disabilities in economically disadvantaged settings: the EasyRoller

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ABSTRACT

Purpose: Stationary training rollers enable wheelchair users to maintain physical health and train as athletes, which serves to treat and prevent immobility-associated chronic disease and improve cardiorespiratory fitness required for sports performance. However, conventional exercise equipment is largely inaccessible for persons with disabilities in low-resource areas, primarily due to cost. The aim of this study was to prototype, develop, and test a portable, cost-efficient stationary training device for wheelchair users in low-resource settings – The EasyRoller.

Materials and methods: Stakeholder input from wheelchair athletes, trainers, and potential commercial manufacturers was solicited and utilized to conceptualize The EasyRoller design. The device was constructed from easily sourced, low cost components, following which it was user-tested with Para athletes. Feedback was analysed and incorporated into newer versions of the prototype.

Results and conclusions: The EasyRoller creatively combines easily-sourced components to significantly cut down cost and ease both manufacture and repair for use in low-resource settings. The device is portable with a total weight of 34 pounds and total size of 42 linear inches while also affordable with a total cost of USD$199. Hereby, The EasyRoller has the potential to increase physical activity participation in populations with impairment who live in socioeconomically deprived world regions.

➤ IMPLICATIONS FOR REHABILITATION

- Exercise and physical activity are key aspects of health and quality of life for persons with disabilities
- Stationary training rollers, devices that enable wheelchair users to train, are often bulky and expensive and therefore inaccessible for populations in socio-economically disadvantaged settings
- The EasyRoller is a portable and affordable training device that increases access to exercise and physical activity for these populations

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Training roller; wheelchair user; exercise equipment; fitness; innovation; physical activity; low-income country

Introduction

Physical activity and exercise are key aspects of health and quality of life [1]. Persons with congenital and/or acquired physical or intellectual impairments are at higher risk of a range of progressive chronic health conditions due to social isolation, lower relative quality of life, and immobility [2–6]. Exercise can be an important mitigating factor for many of these health burdens. The health benefits of aerobic physical activity and exercise for wheelchair users include increased cardiorespiratory capacity [7], and make up part of a holistic strategy (including dietary and lifestyle changes) for primary and secondary cardiometabolic disease prevention in wheelchair users [3,8,9]. Additionally, physical activity, exercise and participation in competitive athletics such as wheelchair racing or wheelchair basketball have been shown to reduce rates of depression and increase life satisfaction in persons with impairment [4,10,11].

Because of these benefits, several countries and organizations have created guidelines for aerobic exercise and strength conditioning in wheelchair users. The World Health Organization (WHO) suggests 75 min per week of high intensity exercise or 150 min per week of moderate intensity exercise [12]. Unfortunately, access to adaptive exercise equipment and opportunities can be challenging for persons with impairment, especially in low-resource settings [13,14]. Limited access, in addition to a small number of available exercise modalities, hampers the potential to maintain mind-body health through exercise. Though an estimated 80% of persons with impairment live in developing countries [15], barriers to adaptive exercise equipment are at their steepest in these global settings, and include product affordability, durability, adaptability, and maintenance and repair costs (Table 1) [16].

Expense remains one of the most significant barriers. Stationary training rollers, which enable the user to remain

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Table 1. Common barriers and facilitators to mobility for persons with disabilities in low resource and tropical settings [16].

Barriers	Facilitators
Psycho-motivational: psychological or emotional barriers that prevent participation in exercise.	Peer support, facility orientations, rehabilitation professionals, athletics coaches
Built or environmental: barriers relating to the physical environment	Ramps, mats to even terrain, door assists, non-slip mats, rails, durable equipment
Cost/economic: ability to afford the cost of participation in wheelchair fitness events or practice	Scholarships, sliding income-adjusted fees, team sponsorships, donations, low-cost equipment
Equipment: availability of specialty exercise and recreational equipment	More adaptive equipment, modifications (such as Velcro straps) to existing equipment, easy repair, local materials
Information: access to knowledge about locations and opportunities to participate in exercise and sport	Education of facility management, advertising for workshops, seminars, and training

stationary with respect to the ground while propelling the chair with their upper body, currently range in cost from between USD$800 to more than USD$2000 [17,18]. To provide context, this amount is comparable to the average annual per capita income for a citizen of Ghana, provided they have an income, which is less likely to be the case among individuals with impairment [19,20]. Additionally, current designs at the low end of the price spectrum are heavy, weighing up to 90 kg (200 lbs), which is impractical for transporting in remote or rural environments. Existing training rollers that are marketed as lightweight and portable, such as those used by Great Britain's Paralympic Athletics Team, come at a much higher cost compared to their heavier counterparts, with a starting price of around USD$1200 [17]. In addition to cost, available equipment is not adaptable to rural settings with uneven and unpaved terrains; furthermore, their usability is severely limited by the capabilities for local repair and maintenance. With all these outlined barriers in mind, the task of accessing equipment and opportunities for physical activity can be perceived as insurmountable, thus creating further isolation and immobility.

There is a clear need for durable, portable, and affordable training rollers for wheelchair users in low-resource settings. Devices currently on the market fail to meet this need. The current study sought to bring together engineers, physicians, and Para athletes to prototype and user-test a product to meet this need, which the research team has called The EasyRoller.

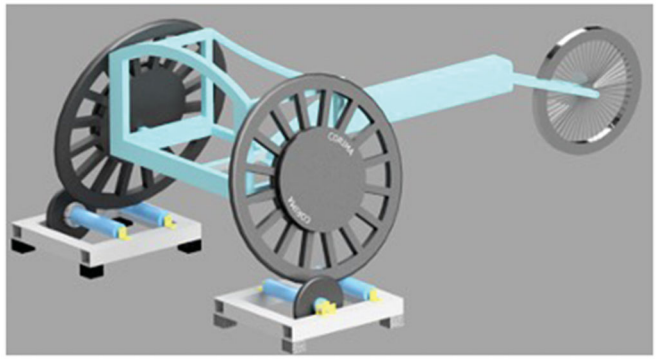

Figure 1. Computer Aided Design (CAD) rendering of The EasyRoller in use with a racing wheelchair. Note that the front wheel stabilizer (wedge recommended) is not shown in this image.

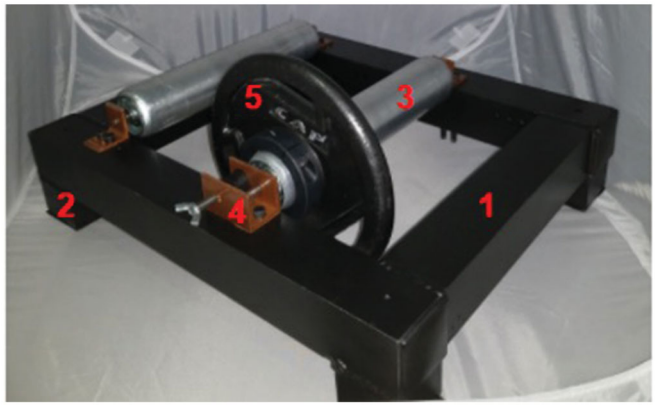

Figure 2. First generation prototype of The EasyRoller. Shown here is one of the two free-standing roller frames with (1) the aluminium frame with (2) raised feet, (3) conveyor rollers, (4) friction disc brake, and (5) inertial weight (5 lb Olympic weight shown).

Materials and methods

Design overview

The EasyRoller (Figure 1) is a low cost, portable training roller designed with components that are easily sourced from hardware suppliers. The primary design consists of two identical free-standing roller frames, one for each rear wheel of the wheelchair (Figure 2). The EasyRoller design was conceptualized through an iterative design process that first involved benchmarking against current wheelchair trainer designs and then soliciting feedback from various stakeholders [21]. These included members of the Go Get Dem Wheelchair Racing Club (GWRC) in Accra Ghana, their athletic trainers and trainers the US, and potential manufacturers of the design. From this feedback, seven design metrics were formulated to make the design accessible and useful to wheelchair users in low-resource settings. These metrics and target values are found in Table 2.

The EasyRoller was designed to fit into a single, compact travelling case and to be set up and broken down quickly and easily. The roller frames are transported pre-assembled with an inertial weight of the athlete's choosing (5 lbs or 10 lbs, gym-style weight plate) locked onto one roller per frame (Figures 1 and 2). Set-up for training then involves two simple steps. First, the athlete or a trainer places the two roller frames on a non-slip, relatively flat ground surface and spaces the frames such that the rear wheels of the wheelchair contact the rollers mid-span. Unlike traditional training rollers, The EasyRoller was found to be relatively insensitive to the precise spacing of the rollers and the tilt (camber) of the wheels. As a second and final step, the front frame or wheel(s) of the chair are then locked in place with available materials, including wooden or foam blocks or wedges. Wood wedges have been found to work well for racing wheelchairs, and foam blocks for sports wheelchairs.

Detailed description

The EasyRoller was designed to be easy and economical to manufacture with commonly sourced materials and off-the-shelf components (Figure 2). The rectangular frames consist of welded

Table 2. Results from testing of The EasyRoller by athletes at the Adaptive Sports Facility in Bristol, CT, compared to the target value.

Design metric	Target value	Achieved value	Reference
Affordability	Material cost under USD$250	Material and labour cost USD$199	Devices currently on the market
Weight	Maximum weight 22.7 kg (50 lbs)	Weight: 15.4 kg (34 lbs)	Luggage restrictions at most airlines [27]
Portability	Total length: <157 linear cm (62″)	Total length: 107 linear cm (42″)	Luggage restrictions at most airlines [27]
Safety	• Holds 113 kg (250 lbs) • Stands <170mm from ground	• Holds 113 kg (250 lbs) • Stands 140 mm from ground	American Society for Testing and Materials (ASTM) standards [22]
Adaptability	• Stable on various surfaces • Compatible with racing and sports wheelchairs	• Stable on indoor court and outdoor uneven grassy terrain • Compatible with racing and sports wheelchairs	• End-user input • End-user input
Easy to manufacture and repair	Estimated bulk manufacturing 20,000 units yearly	t.b.d.	UK-based company Motivation [28]
Functionality	• Effective stimulation of track workout • Including >1 resistance level	• Effective workout experienced • >1 resistance level	• End-user input (GWRC) • End-user input (GWRC)

stock aluminium box tubing (2-inch square with 1/8-inch wall thickness). Standard conveyor rollers (2-inch diameter, 2 million cycle life) were secured to the top of the frame *via* welded L-brackets. These commonly available stock rollers inherently include a spring-loaded axle that allows for easy removal. Conveniently, Olympic-sized weight plates (2-inch diameter hole) snugly fit over these rollers and act as inertial weights. Both 2.5 pounds (lbs) and 5 pounds (lbs) weights can be accommodated with the height of the frame as shown. The inertial weights are held in place by tube clamps, with hose clamps or zip-ties also serving this function. The EasyRoller also includes a resistance adjustment feature that consists of a simple friction brake. A nylon plug is advanced against the end of one of the rollers *via* a hand-tightened screw. The user can easily adjust the tension by reaching down and adjusting the screw.

Results

The findings of this study are presented here, where several aspects of The EasyRoller were analysed by obtaining quantitative feedback through testing of the device by the team of engineers at the University of Delaware. Additional aspects of The EasyRoller were analysed through field testing and interviews with end-users at an adaptive sports facility in Bristol Connecticut, US, who provided qualitative feedback on the design. All end-users were players on the local wheelchair basketball team, and field testing took place following the principles of the Declaration of Helsinki.

Quantitative feedback

A first-generation prototype of The EasyRoller system (Figure 2) was used for benchtop and early field testing. The system achieved the target metrics for affordability, portability, compatibility and adaptability (Table 2). Cost of goods, including fabrication costs for welding and machining, was USD$199. Cost savings were done primarily by using stock materials for framing, rollers, and inertial weights. The EasyRoller system was also highly portable, with a total weight of 15.4 kg (34 lbs) and packed dimensions of 106.7 linear cm (42″), both of which are compatible with airline travel regulations. Early field testing demonstrated that The EasyRoller could accommodate daily use, sports and racing wheelchair frames, demonstrating the compatibility of the device. Lastly, the device was found to be stable when in use on an indoor surface such as a basketball court, as well as outdoors when tacky surface (e.g. yoga mat) was used to increase stability and ease of setup.

The aspects of safety, ease of manufacture and repair and functionality were largely met (Table 2). For example, for safety, The EasyRoller can hold at least 113 kg (250 lbs) and stands 140 mm from the ground in compliance with American Society for Testing and Materials (ASTM) standards [22]. The device was easily manufactured by engineers at the University of Delaware due to the use of easily sourced and off-the-shelf components and from user-feedback it can be concluded that The EasyRoller functions for the purpose of exercise while providing various resistance levels. From end-user-testing at the adaptive sports facility, it was concluded that adding Olympic weights of 5 lbs to the rollers provided the desired feel of momentum, with an average free rolling time of 3.5 s – meaning the rollers stopped moving 3.5 s after the users stopped pushing the chair. The 2.5 lbs weight did not increase the free rolling enough and 10 lbs required too much user exertion. The athletes also mentioned that maintaining momentum and stability is preferred over simulating a track workout when defining functionality. However, they "felt like they could get the desired workout".

Qualitative feedback

Athletes who tested The EasyRoller play for a local wheelchair basketball team at the adaptive sports facility. They did not buy their own equipment, rather, they received it with the aid of grant funding through agencies such as Disabled Sports USA. The athletes had a conventional stationary training roller, the Wheelers' Paramill, available for training at their facility and were experienced users of this traditional device [23]. It is important to note that they were physically fit wheelchair users, playing basketball and doing weight-training about five times per week. Field testing and interviewing took place on an indoor basketball court.

After the first round of The EasyRoller testing, one of the athletes mentioned, "all in all, I thought it was a very positive experience and the device seemed user friendly". He liked how he was able to get a lot of repetitions in a short amount of time and was excited about "the idea of being able to put this device in a suitcase and walk away with it". Further feedback underscored accessibility, portability and affordability:

> The most important things about The EasyRoller are, number one, the fact that it provides access to physical activity, specifically cardiovascular exercise, for fulltime or part-time chair users. Number two, the portability aspect of it and the ability of taking to people

> where they are instead of them having to come a gym, that is huge. The third thing is the price breakdown; it is very reasonable for what you are offering. You are going to open yourself up to a lot of people being able to purchase it, or to be able to get small support.

Furthermore, one of the coaches emphasized how The EasyRoller would not only be beneficial from the perspective of the athlete, but also from a coaching standpoint. The coach of the youth and women's team at the adaptive sports facility mentioned how The EasyRoller may allow him to train more easily with his athletes from various regions around the country:

> I think if I had something that is truly portable and that I could move places, from a coaching standpoint I think that would be great. In my women's basketball team for example, we have 13 ladies from about 5 different states. If it was something where I could meet an athlete somewhere and we could train together, and I could bring the roller with me I think that would be a great advance.

Besides serving athletes and coaches, The EasyRoller could be beneficial to any wheelchair user. Although testing was performed at an athletic facility with wheelchair users who train as athletes, respondents mentioned how The EasyRoller would benefit any wheelchair user interested in staying in shape or maintaining healthy exercise practices. Without such device, wheelchair users look for safe outdoor trails and tracks, many of which are inaccessible. One end-user criticized the three outdoor tracks in his area that are open to public, none of which are accessible for wheelchair users. According to him, inaccessibility is one of the key limiting factors to exercise. He said about The EasyRoller how "it also provides a level of independence that our community really strives for".

Additionally, one respondent mentioned the positive impact The EasyRoller could have on mental health. According to him, being able to push when primarily home-bound and with limited access to physical activity, is important with regard to mental well-being. This feedback was obtained during the global COVID-19 pandemic [24], when he was required to stay at home; an enormous contrast to his "normal" physically active lifestyle. This highlighted the potential impact The EasyRoller can have on mental health:

> The rate of depression for people who don't have access to the outside world is so high, even when you are not in this COVID situation. If you are not able to leave your space is it hard not to get into a level of depression. Even the two days being locked into my apartment is too much for me. If I were in this situation full-time and did not have something like the roller that gives you something to block everything else out and just go, that would be hard.

Athletes did comment that one of the drawbacks of The EasyRoller, when compared to a workout on the court or a track, is "not having that extra roll when you push". However, they said they experienced this same issue on their current large and expensive training rollers; it did not feel the same as if you were on the street or court to them because they did not get a certain momentum. When the same athletes were asked about the relevance of this disadvantage they said:

> I think the [Easy Roller] machine itself, despite it not having the extra inertia, it still is a pretty good representation of a natural push stroke, whereas some of the previous roller devices, because of how it lifted the chair and put it in its position, did not even feel like a natural push stroke, whereas this at least feel natural except for the lack of inertia piece.

Discussion

Despite ongoing global efforts to expand opportunities, events, and platforms for persons with impairment to participate in physical activity and sport [25], there remains a gap in access, utilization, and enjoyment for those in resource-limited settings. The EasyRoller has the potential to help close this gap by increasing global access to physical activity by abating the issues of 1) cost, 2) weight, 3) portability, 4) safety, 5) adaptability, 6) ease of production/maintenance, and 7) functionality through targeted design metrics (Table 2).

Cost

To address the issue of cost, The EasyRoller creatively combines commonly sourced and off-the-shelf components, to significantly cut down cost of materials and production. Total estimated cost for materials and labour is USD$199, setting The EasyRoller under the target cost of USD$250. It can potentially retail for less than half the price of current standard training rollers offered, that start from retail prices of USD$800 [17,18]. The standard training rollers are normally quite heavy however, thus a more appropriate sense of the cost reduction is to compare The EasyRoller to portable training rollers such as those used by Great Britain's Paralympic athletics team, DynoLight Rollers, which retail for prices starting from USD$1200 [17]. Thus, retail prices of such devices compare to six times the cost of materials and labour of The EasyRoller, demonstrating a substantial potential reduction in retail price. From this we can conclude that The EasyRoller is a much more affordable, portable training device for wheelchair users globally. Although the initial target was wheelchair users in resource-poor settings, end-user testing demonstrated that there is a great need for such affordable device in high-income countries as well. Further, despite this cost reduction, end-user testing has shown promising results in its functionality with no significant decrease in satisfaction, promising an excellent price-performance ratio for The EasyRoller.

Weight

To address the issue of weight, The EasyRoller used commonly available, lightweight materials such as aluminium. By combining off-the-shelf small diameter conveyor rollers with a free Olympic weight plate, a sufficient moment of inertia was created, avoiding the need to use large and heavy rollers as found on most current equipment. The complete EasyRoller assembly has a total weight of 15.4 kg (34 lbs) which is quite light compared to most similar training rollers available on the market, such as those manufactured by McClain and Top End, who have a total weight of up to 90 kg (200lbs); this is almost six times heavier than The EasyRoller.

Portability

Portability is an important factor, particularly in low-resource settings. Distribution of the product to rural areas was of primary concern and thus the design needed to be compact. Discussion with Para athletes from the West African sub-region inspired designers to create a system that could travel with athletes to competitions and other events so as not to put them at a training disadvantage when compared to competitors from high-resource settings. Discussion with end-users in the US further revealed that a compact design was extremely desirable amongst coaches in high-income countries as well, as it allowed flexibility in training site selection, and did not result in being restricted to one physical location. The current design has a total length of 106.7 linear cm (42″) and easily fits into a suitcase that meets standard checked luggage weight and size requirements for most

commercial airlines – namely a maximum allowance of 22.7 kg (50 lbs) and 157 linear cm (62″).

Safety and adaptability

With the reduction of weight and size, the team wanted to ensure appropriate safety standards were maintained, quality materials were utilized, and that the product was durable. Thus, the design was tested against and m*et a*ll ASTM standards user weight (113 kg, 250 lbs) and vertical height (<170 mm) requirements. The product design consists of two identical roller frames that can be adjusted to accommodate a wide range of wheelchair designs and is adaptable for use on indoor courts, outdoor uneven grassy surfaces, or even within the home of a user. User testing with different Para athletes has shown the compatibility of the device with different locations and wheelchair designs (racing and sports wheelchairs) by using different front stabilizers, confirming its versatility to adapt to the need of the user.

Ease of production and maintenance

Ease of production and maintenance was achieved by using components that are easily sourced and can be assembled by anyone with basic welding expertise. This creates potential opportunity for bulk manufacturing and assembly in various global settings.

Functionality

Lastly, The EasyRoller needed to be functional and create an effective simulation of a track workout. Users in disadvantaged settings often lack access to surfaces that enable high speed thus limiting training opportunities. Although feedback from end-user testing demonstrated that the device did not allow a perfect simulation of a track or court workout, this was not found to be a substantial shortcoming. The EasyRoller functions similar to the conventional bulky training rollers in this regard, while being considerably more portable and affordable. In addition, the product was designed to have more than 1 resistance level to offer different training modes and experiences – both cardio-centric and strength-centric.

Future directions

With improvement, The EasyRoller training device has the potential to increase athletic participation among wheelchair users worldwide, including socioeconomically deprived regions, through meeting the proposed metrics (Table 2). Since the production of The EasyRoller, multiple athletes from around the world have reached out to ask about further development, demonstrating the need for such device in the marketplace of stationary training rollers. It is expected that this device and others like it can generate significant physical and socioemotional benefit – a benefit that has been shown to be missing in many areas around the world.

Case studies from Malaysia and Ghana show the potential impact that access to this economical, light weight roller could have.

1. Malaysia has a long tradition in Para sport, having first entered international competition in 1970, nearly 6 years before the first Paralympics games were ever held. Despite the countries forward-thinking athletes, continually low overall participation rates and shortages of funding and equipment frustrate regional progress in Para sport [14]. Notwithstanding these challenges, many athletes who participate in Malaysia's Para sport programmes cite the positive health benefits, increases in life satisfaction, and feelings of achievement through exercise and sport [14].
2. The Ghana-based not for profit organization, Go Get Dem Wheelchair Racing Club (GWRC) seeks to improve the lives of disabled persons, especially disabled youth in Ghana and throughout Africa, through sport. In order to function, the club constantly has to confront a lack of stable government support, little usable infrastructure in largely rural environments, as well as the limited access to training equipment [26]. Although organizations like GWRC have worked hard to overcome these barriers, recently enabling several Ghanaian Para athletes to compete in the Paralympics, these found for opportunities are still quite limited to a few lucky athletes. The wider wheelchair community in the country as well as other racing clubs are in dire need of affordable and portable training equipment such as The EasyRoller.

Although resource-poor settings were the original focus of this study, clear benefits for wheelchair users in high-income countries have also been demonstrated throughout this study and the target group can be expanded to impact a greater audience, including those who are temporarily or permanently confined to their homes, and those without transportation or other types of support to get to local fitness or health facilities, tracks, trails, or paved paths. Additionally, any Para sport coach, personal trainer, or physical therapist could use such a device to train participants in diverse locations.

Limitations

The current research did have limitations. Additional tests need to be undertaken to further confirm the durability and safety of the design. Although the supplier states that the lifecycle of the conveyer roller bearings is ∼2.2 million rotations, lifecycle testing and stress testing of The EasyRoller in its complete set-up should be performed to this number of rotations to guarantee safety. In addition, the adaptive chucks used to stabilize the front wheels and casters need to be further developed to enhance stability during use with both sports and racing chairs. Although initial end-user testing for feedback was performed, a more comprehensive survey over a longer period of time would be beneficial to gain a full understanding of functionality. Several end-users suggested modifications to the design to include a ramp to allow independent transfer on and off the device more easily, pre-set markings on the (yoga) mat to allow for easier set-up, and a larger handle to the resistance mechanism to eliminate the user's need to reach down to adjust resistance. Incorporation of these suggestions may help make The EasyRoller even more user friendly. An additional limitation was the fact that opportunities for on-site production in resource-poor settings were not explored in this study. Workshops located in main cities of countries like Ghana and Malaysia are potential sites to gain further understanding of the possibilities of local manufacturing.

Conclusion

Consistent with our initial marketplace analysis, discussions with athlete-testers, a review of two case studies, and personal observations, made it clear that there is a gap in accessibility to appropriate exercise equipment for wheelchair users, particularly in poor settings. The EasyRoller is one solution to this dearth of opportunity, offering a low-cost, portable, easily maintained, environment-appropriate exercise equipment for wheelchair users

around the world – no matter their situation. Through incorporating a novel functional and affordable design, The EasyRoller has the potential to increase athletic participation among physically impaired populations in socioeconomically deprived regions globally and empower millions of physically disabled individuals worldwide to improve their health, social, and emotional wellbeing.

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Disclosure statement

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