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RESEARCH PAPER

'It's more than just a running leg': a qualitative study of running-specific prosthesis use by children and youth with lower limb absence

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ABSTRACT

Purpose: The purpose of this study was to investigate the use of running-specific prostheses (RSPs) by children with lower limb absence (LLA) along with the benefits and challenges of RSPs.

Materials and methods: In this descriptive qualitative study, eight children (ages 8–20 years) and their parents participated in semi-structured interviews. The interviews were audio-recorded and transcribed. Coded data were the foundation for central theme development.

Results: Three main themes were generated. "Run faster, jump higher, do more" (the benefits of RSP use), "Every leg serves its purpose" (comparing functionality between daily use prostheses and RSPs), and "A lot more to think about" (additional considerations with RSP use).

Conclusions: RSPs have a positive impact in promoting children's engagement in sports and physical activities. While some children used their RSP primarily for running, others wore it for a broader range of physical activities. Issues with balance and discomfort caused by leg length discrepancies and/or ill-fitting sockets limited daily wear time. Limitations related to current RSP designs and clinical implementation should be addressed to optimize the functional potential of children with unilateral or bilateral LLA.

➤ IMPLICATIONS FOR REHABILITATION

- Running-specific prostheses (RSPs) positively impacted children's ability to participate in some sports with peers promoting their physical and social well-being.
- The main issues that children faced were discomfort, difficulty balancing, and inability to use RSPs for certain sports, while parents' issues focused on supporting prosthesis use and transport, and adjustments of different prostheses to keep up with their child's growth.
- Clinicians should be aware of the challenges of RSP use to best support children and their families.
- Designers should focus on addressing limitations with current RSPs to facilitate the diverse needs of pediatric users.

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Introduction

Participation in sports and physical activities has well-established physical and mental health benefits [1,2] for children [3,4]. Those with lower limb absence (LLA) have an increased risk of developing chronic conditions due to inactivity when compared to their typically developing peers [5]. Physical activity plays an important role in mitigating this risk, but challenges with their lower limb prostheses can restrict or completely discourage a child with LLA from participating [6].

Children with LLA are generally prescribed a daily-use prosthesis (DUP) for primary use; however, DUPs have limited functionality that can hinder their ability to perform sport-specific skills such as running, skipping, dodging, pivoting, or jumping [4]. This limited functionality is associated with the relatively rigid shank, ankle, and heel components that do not offer sufficient energy absorption/generation to mimic the movements of the biological ankle joint [7]. Consequently, children with LLA rely on an array of advanced sport/activity-specific prosthetic components for better athletic engagement [8]. Examples of these prosthetic components are cycling legs, swim legs, and running-specific prostheses (RSPs) [9]. RSPs provide impact absorption and energy-storage through the deformation of the curved carbon fiber blade and thus enable high-impact activities such as running, sprinting, and jumping [10,11]. RSPs also typically lack a heel component and thus provide greater energy-return capabilities which differentiates them from other prostheses, such as dynamic elastic response prostheses (DERP) or crossover feet.

While RSPs are commonly used by athletes in competitive sports, their availability and use for recreational activities has recently expanded within adult and pediatric populations [12]. Prescription of an RSP to an active individual with LLA for everyday sport and recreational activities is becoming more common in clinical practice. The practice is driven by the individual's personal goals, or in the case of pediatrics, also by parents' hopes for their child, and is facilitated by availability of funding mechanisms for secondary devices [13].

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Supplemental data for this article can be accessed here.

In elite athletes, RSPs have been shown to increase performance levels to match able-bodied runners at similar energy costs [14]. However, limited studies have examined the benefits and challenges of RSPs from the perspective of recreational users [12] and no studies have focused on use by children. To address this knowledge gap, the aim of this study was to investigate how children use their RSPs and to learn about the impact of RSP use on their ability to participate in sports and activities. By employing interviews to obtain first-hand experiences of children who use RSPs and their parents, the benefits and the challenges of RSPs could be directly explored. Such evidence could help guide clinical practice, improve patient outcomes, and optimize best use of healthcare resources.

Methods

Study design

In this prospective cross-sectional study, a descriptive qualitative approach [15,16] was used consisting of interviews with children who use RSPs (with the option for parent joint participation as desired). This approach is often used when direct, rich descriptions of phenomenon are desired, especially when analyzing topics that are new [15]. Analysis within descriptive qualitative research usually employs a content analysis approach to stay close to the data rather than using an interpretive lens [16]. The Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist was followed to report important characteristics pertaining to study rigor and methodology [17]. It should also be noted that the study was conducted during the COVID-19 pandemic, hence many aspects including the data collection were conducted virtually (e.g., using video conferencing).

Participants

Study participants were recruited from an outpatient clinic in a tertiary care pediatric rehabilitation hospital. The inclusion criteria for child participants were: (1) age between 8 and 20 years, (2) any level or cause of LLA – congenital or acquired amputation(s), (3) current RSP user, and (4) able to communicate in English. The inclusion criteria for parent participants were: (1) be the parent/guardian of a child with LLA who is participating in the study and (2) able to communicate in English. There were no exclusion criteria.

Participants were identified through health records and compiled jointly by clinicians at the tertiary clinic as per the facility's Research Ethics Board approval. The compiled list consisted of 17 clients who were contacted by their clinician either by phone or email and provided with a study invitation. Ten clients responded and consented to being contacted by the research manager to learn more about the study and schedule the interview if they then wished to participate. There were no relationships between the study participants and the researchers. To the researchers' knowledge, study participants were not known to each other. Verbal consent was obtained by the research manager via video conference from the child before commencing the child's interview, and by parents who wished to take part in their child's interview.

Data collection

Child participants completed a brief online study-specific activity survey (SurveyMonkey, San Mateo, CA) prior to the interview. The survey questions examined the sports and activities the child engaged in. A list of different sports was provided based on the Physical Activity Questionnaire (PAQ) [18]. This survey functioned as a topic sensitizing tool used to encourage recollection of the range of activities completed using RSPs that could then be discussed further in the interview.

Interviews were conducted via video conference (Zoom Video Communications, Inc., San Jose, CA) by FHM who followed a semi-structured interview guide created by the research team for the study (refer to Supplemental table 1). The interviewer received training by conducting mock interviews with senior researchers experienced in interview-based pediatric rehabilitation research. The interview guide was reviewed by two physiotherapists and a prosthetist at the hospital clinic with respect to the comprehensiveness of the content and clarity of wording. Each interview was conducted in a single session and audio recorded. Notes were taken by the interviewer to guide clarifying questions as well as providing additional information for review of interview responses in which a participant would gesture or present something to the camera such as their RSP or DUP. Interviews with the child and parent began by FHM discussing the goals of the research and the interview (as described in the information and consent letter).

The children were the primary interviewees, but their parents/guardians were invited to also participate. Parents are considered to be valuable informational proxies for children when the child is too young to be able to self-report or the information required needs additional context (e.g., in this study for questions related to initial prescription decisions, funding, etc.) [19]. Participating parents sat beside their child during the interview; however, the child was given priority in answering each of the questions first. Interviews were conducted until informational saturation was achieved, such that subsequent interviews did not lead to the addition of new codes in the iterative analysis described below [20]. All interviews were conducted during the COVID-19 pandemic when lockdowns had resulted in the closure of schools and placed limitations on children's ability to engage in physical activities, especially with peers. At the time of the interview, the lockdown had been in effect for 4–5 months. During the interviews, children were asked to recollect their experiences prior to the global pandemic.

Data analysis

Interviews were manually transcribed by HZ and verified for accuracy by FHM. The transcripts were not returned to the participants for review or comment. Content analysis was performed on the interviews using the steps outlined by Braun and Clarke [21,22]. Specifically, two researchers (FHM and HZ) independently coded the first three interviews using a data-driven (i.e., inductive) content analysis approach, to generate the initial codebook [23]. These codes were reviewed, amended, and finalized by FHM, HZ, FVW, KK, and JA at a study meeting. The remainder of the interviews were coded according to this codebook with revisions and additions as needed, and previous interviews were reviewed by FHM to incorporate any coding changes. This was followed by analytical coding where descriptive codes were grouped into categories to assist in the generation of primary themes that recurred across the data. In this way, coding translated to the interpretation and reflection on meaning [24]. The theme titles used the language of the participants to best represent their perspectives. All data analyses were conducted using the qualitative data analysis software NVivo 12.0 (QSR International, Cambridge, MA).

Analysis trustworthiness was established through consideration of credibility, dependability, and transferability [25]. The inclusion

Table 1. Study participant demographics, prostheses details, and sport participation details.

ID	Age (years)	Amputation type and level	Experience using RSPs (years)	Main sports/activities with RSP[a]
C1	12	Bilateral transtibial	4	Running, basketball, gym
C2	10	Unilateral transtibial	1	Gym
C3	14	Unilateral transtibial	2–3	Running, gym
C4	20	Unilateral ankle disarticulation	6	Running (track and field)
C5	11	Bilateral knee disarticulation	5	Running, gym
C6	17	Unilateral transtibial	3	Running (cross-country)
C7	8	Bilateral transtibial	5	Running, gym
C8	9	Unilateral transtibial	2	Gymnastics, gym

[a]Gym refers to any free-form sport that was done during gym class at school.

of children with different levels of experience using RSPs, age groups, and genders supported credibility and provided a means to explore the phenomenon from different perspectives [25]. Study dependability was supported by open study dialogues among authors representing the fields of pediatric clinical prosthetics, pediatric physiotherapy, prosthetic design (engineering), and clinical research [26]. Finally, transferability of the research was aided by reporting relevant study participant demographics to aid with the contextualization of study findings [27].

Results

Of the 17 potential study participants that were contacted by clinicians, 10 responded and consented to being contacted by the research team. Two of these 10 participants chose not to participate, while eight were recruited (8–20 years old, four males and four females) and took part in the interviews. In four of the eight interviews, the child's mother chose to join their child as a participant. Interviews lasted from 30 to 70 min. Table 1 provides a breakdown of the participants' key characteristics. Details of gender and diagnosis were omitted from the table to maintain the confidentiality of the child's identity. Most study participants reported wearing their RSP only during a specific activity. For example, they would switch into their RSP at the start of gym class and then switch back into their DUP after. The most commonly reported RSP activity was running. Other sports included soccer, basketball, and gymnastics. RSPs were also used for playing during recess, going for walks, etc.

Quotes from study participants exemplifying the themes are provided verbatim in the text. The quotes that best describe the experiences and thoughts of the children have been included for each theme, meaning that selected quotes are not evenly distributed among study participants as far as representation. However, all participant responses were given equal weight during the data coding and analysis process. Since the children were given the primary voice, parents' quotes were only included if they contained additional insights. In these quotes, to maintain confidentiality, child participants are reported with a "C" and ID number and parent participants are reported with a "P" and the corresponding ID number. The terms "everyday leg", "regular leg", and "normal leg" were used by study participants to name their DUP, while the terms "running leg", "running blade", "jogging leg", and "sprinting leg" were used to refer to their RSPs.

Three themes were identified: "Run faster, jump higher, do more" discusses the benefits of RSP use, "Every leg serves its purpose" compares the functionality between RSPs and DUPs, and "A lot more to think about" explores additional considerations with RSP use. These themes were developed by organizing the data into a concept map as shown in Figure 1.

Theme 1: Run faster, jump higher, do more

This theme explores the main benefits of and reasons for using an RSP. It explores how RSPs impact the ability to play with friends or compete with peers, and how wearing an RSP makes children feel. It also explores the inspiration and motivation for obtaining an RSP, and parents' perceived impact of the RSP on their child.

All child participants indicated that having an RSP allowed them to move more quickly and jump better than with their DUP. As one child said:

> You can run better and jump really, really high and act like a kangaroo! And it's really fun! (C8)

Participants shared how this added mobility let them participate in some of the same activities as their able-bodied peers, and how this opened opportunities that they did not have with their DUP. For some, this meant regaining abilities that they had lost due to their amputation.

> Before they get them [RSPs], I think a lot of amputees are pretty … It's easy to be depressed since you feel like you've lost so much, and I would just tell them that you're going to be able to do pretty much everything that you used to be able to do again, so have hope. (C6)

The participants also recounted experiences of how RSPs affected their ability to play sports. These included playing tag, being able to bounce during gymnastics, competing in races, participating in a marathon with a running group, playing badminton, and competing in track and field races.

For one participant, having the running leg helped in achieving a personal milestone.

> I would say running the 10K felt really good because that was the farthest I had ever run. Even before my amputation, I only ever ran 9K, so getting to 10K for the first time in my training, that felt really awesome. (C6)

The participants also talked about how the ability to run faster gave them more self-confidence to try new things, and thus made them more active. Parents echoed these feelings.

One parent described how her child expressed feeling left out at school before they received their RSP because they were unable to take part in the games with their friends. She went on to say that the RSP is just as important as the DUP for her child:

> The running legs are also something that they need in their everyday life growing up, it's not- it's a necessity, it's not like a recreational device, … I mean [not having an RSP] would prevent [their] self-esteem from being able to do other things that other kids could do. (P5)

Indeed, when asked how wearing an RSP makes them feel, all the children expressed positive sentiments, using words such as "free", "happy", "awesome", "springy", "makes you want to run", "fun", and "fast". The participants unanimously expressed that they like how the RSP looks (e.g., it "looks cool"). The ability to decorate and customize their RSP with stickers, colors, and

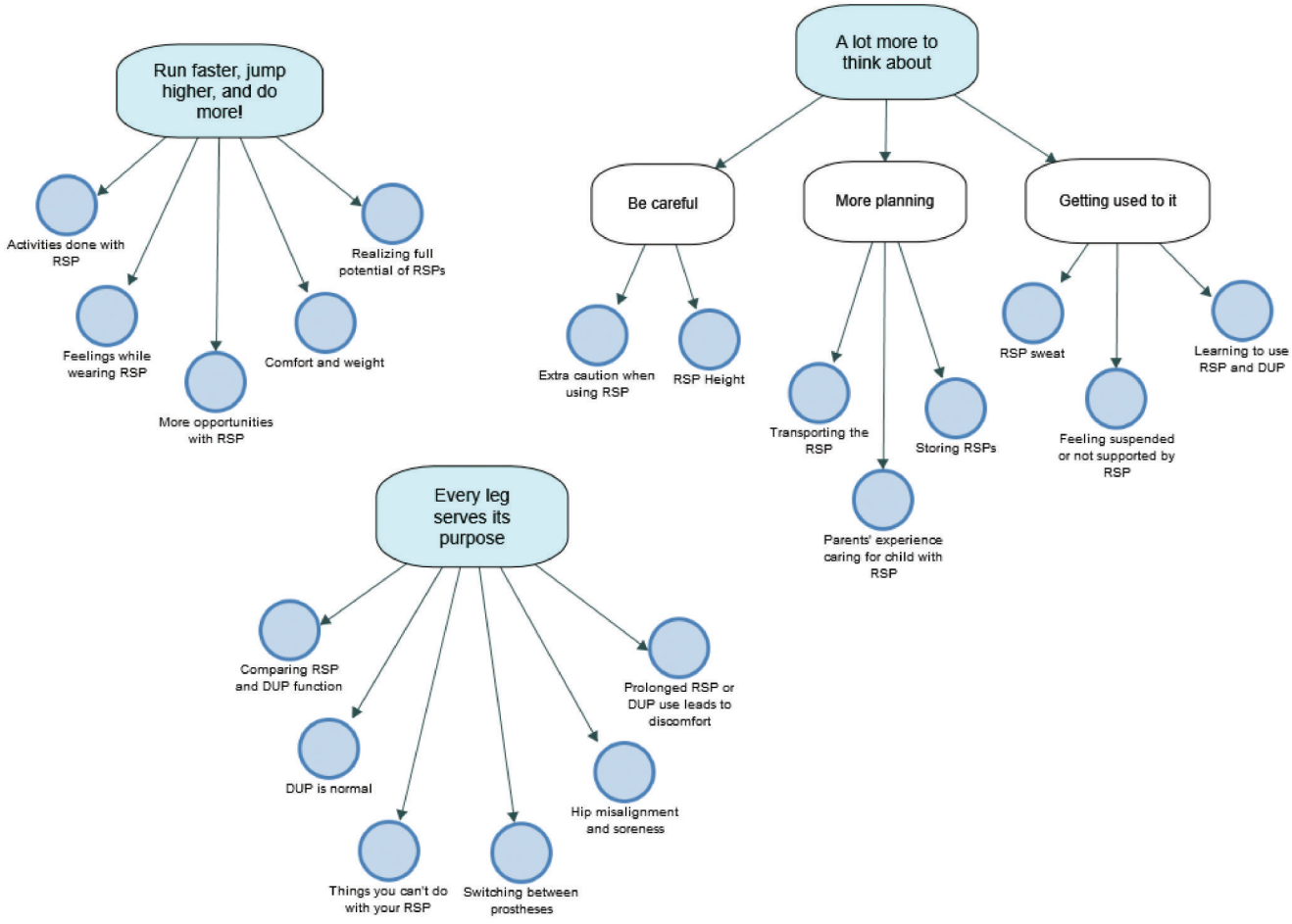

Figure 1. Thematic concept map showing the final three themes (light blue), subthemes (white), and codes (dark blue). The figure shows a later iteration of the concept map with some representative codes selected from the complete codebook.

patterns was mentioned a few times, and one parent expressed that their child's opinion on how the prosthesis looks directly affects how often they want to wear it.

With respect to the reactions of friends, peers, and strangers to wearing an RSP, participants expressed that they would typically get asked about what the RSP is and whether it is comfortable. Although the children varied in how they felt about being asked these questions (i.e., some found the questions annoying and others enjoyed the interactions), these interactions did not hinder RSP use around others.

Children also compared the weight of their RSP to the DUP, with all but two expressing that their RSP was "much lighter", and this helped them run faster and further.

> "So when I run with my running legs, it feels like it's just a feather on my leg. It is super light!" … "[My DUP] is like a lightish rock." (C7)

However, even the two children whose RSPs felt heavier than their DUPs noted that they benefited from running faster and further with the RSP.

Most of the children heard about RSPs and became inspired to get an RSP after witnessing someone else using one, whether this was through amputee society meetings or interactions at their prosthetic clinic. One child described meeting an amputee athlete who inspired them.

> She was kind of like my role model since I was a little [child] … when she started getting into running and got her running leg, that's where I was like, oh my god, I want one of those too! (C4)

In contrast, one child shared that they were initially afraid to use their new RSP because of their fear of falling due to the curved shape of the prosthesis. The child explained that it was not until having the chance to try it that they felt comfortable using it.

When asked if they had known what an RSP could be used for before having been prescribed one, many respondents thought that it could only be used for running while some added the potential utility of using the RSP as a backup prosthesis. They tended to become aware of the full potential of the RSP only after they started using it.

Theme 2: Every leg serves its purpose

This theme explores how children use their RSP, how their RSP compares to their DUP and their experience, and reasons for switching between prostheses. When asked about what they liked about their DUP, children mentioned appreciating the comfort in being able to walk and do "everyday things", its normalcy, especially from a cosmesis standpoint, and the ability to wear different footwear.

> Okay for my everyday leg, I really like it because it's just like, it's not anything special but it's not anything, not special, it's just completely normal and that's what I like about it. (C1)

> [The DUP] just does the job, you know? … It's not heavy, it's not clunky, um, it just suits my needs … It serves its purpose. (C4)

However, they discussed the difficulty of running with their DUP in contrast to the increased functionality of the RSP.

> I originally learned to run on my everyday leg … It was very uncomfortable. Because there's no spring, so you're just landing hard on it every time. But I can kind of run [with my DUP] – like if I'm trying to catch a bus or something, I can – I can hustle. (C6)

While some contrasted the experience to running on their everyday device as in the previous quote, others indicated that they ran for the first time after they received their RSP.

> Well, I knew I could run [when I wear my RSP] but I didn't think it would be as fast as it actually was. Because that was my first time running. (C1)

One child reflected on being able to reach a higher level of functionality and mobility when using their RSP instead of their DUP for sports.

> I played a lot of sports when I was younger, but that was always on my everyday leg that has no function, and just is kind of … there … So, um, going from that and then running on the jogging leg it felt like I was so free and had the ability to move so much quicker … I just instantly was able to experience a whole other level of functionality and mobility. … When I was younger, I guess I really never thought too much about my lack of mobility when it came to playing. Now I look back and I was like, oh my god, how did I do all this activity on this leg? (C4)

The frequency of RSP use varied from daily to once weekly. Some mentioned that it was strictly used for running (Table 1) while others described use for different sports and physical activities. They described using their RSP both indoors (e.g., playing in the gym) and outdoors (e.g., playing soccer on a grass field). Although RSP users acknowledged the added difficulty of playing on uneven surfaces such as grass, this did not limit them from participating in the activity taking place there. The children agreed that it mattered more what activity they were doing rather than where it was happening.

The experience of switching between prostheses was considered either a minor inconvenience or an annoyance as shown in the following contrasting quotes.

> I don't really mind um, just switching to my everyday leg, I mean, it's just a minor inconvenience. Sometimes I do wish that I could just start running whenever I want, just, like, … drop my bag off somewhere and go for a run, but, running is pretty comfortable on my running leg, and walking is comfortable on my everyday leg. So, I don't really mind switching back and forth. (C6)

> It's pretty annoying to switch between them, you have to like, take it off, take it all off depending on which leg, but you have to take it off, then re-put it on, and it's like, it takes quite a while, especially when they're really tight, you want to put them on properly the first time, because it's just – it's really annoying to re-put it on. (C8)

In their decision-making about which leg to wear, there were three main reasons that seemed to motivate the child to switch between prostheses: (1) difficulty balancing, (2) challenges with sport-specific skills, and/or (3) discomfort due to leg length discrepancies and prolonged use. due to leg length discrepancies. These are described briefly below.

1. Children noted difficulty in static balance with the compliant RSP compared to the rigid DUP.

> I can't really stand still with [my RSPs] because there's a lot of spring and stuff, but um, balance is okay whenever I'm running … and walking. (C5)

2. Sport-specific skills such as start–stop motions, backwards motions, or kicking a soccer ball were found to be difficult with the RSP, while turning and changing direction were not.

> You're not supposed to do soccer with your running leg … because [the ball] sort of gets stuck, in the hole [the curvature of the RSP blade] … and then you can't really get it out. (C8)
> Changing directions, I mean, the- it's fine. It's just sometimes when I want to stop, if I'm going really fast, I don't want to stop suddenly because I could fall over, because it's not balanced all the way because it's curved. (C3)

3. Discomfort due to leg length discrepancies was reported by children with unilateral amputations. RSP limbs are typically designed to be longer than biological limbs to accommodate the deformation of the blade during running. This asymmetry made it uncomfortable and at times painful to do non-running tasks. Children and parents expressed a desire to have the RSP to act more like the DUP at times.

> [I use my RSP] just for running because it's so much … taller than my other leg … So, my hip alignment's off when I just walk, and it gives me back pain if I walk on it too long. Like, if I stand on my tip-toes as much as I can, then it's about aligned. But it's, kind of hard to walk like that. (C6)

Discomfort was also caused by prolonged RSP wear. One child participant explained that their leg tends to "freeze up" and that they would lose sensation or have a feeling of pins and needles.

> Oh yeah, and when I wear it a lot it hurts my leg sometimes … like every, every side is pushing my [leg] and squeezing it. So, I have to take it off. (C2)

Another noted issue was that at times neither the RSP nor the DUP was sufficient to complete the task at hand. In this example, an RSP user described their experience pacing during cross-country running.

> It is kind of annoying that … if I'm running too slow, where my hips aren't quite even and then my back kind of hurts. (C6)

In another instance, despite having two RSPs, one dedicated for jogging and the other for sprinting, a child described their experience traversing hills and finding that neither leg entirely suited the task.

> It's just tough because my jogging blade … it really doesn't give me enough and then my sprinting leg is like almost a little too much for some of the hills I run. (C4)

Theme 3: A lot to think about

This theme discusses the realities and practical considerations with RSP use which include RSP design-based challenges that users face, learning to use an RSP, parents' RSP-related experiences and financial considerations. It is divided into three subthemes: "Be more careful", "Getting used to it", and "More planning".

Subtheme 1: Be more careful

Children discussed how additional caution is needed to safely use an RSP. One child shared their experience during cross-country running when attempting to traverse uneven terrain.

> I did cross-country in grade 10, and … there was so many roots and rocks everywhere and stuff, so that was hard just because my running leg was built for cement, it was not built for … forests or whatever. So landing on rocks … it's like, the blade is so thin and there isn't very much that comes in contact with the ground, so it just makes it very – if you're not on a flat surface – then it makes it very unstable and easy for it to shift and fall off, and then also, because it's so thin, roots were a very big problem … it could slide under them really easily without me knowing … I had to be really careful. (C6)

The longer length of the RSP also led to a need to exercise additional caution when standing or walking to avoid tripping or

getting the RSP caught. In addition, children discussed the difficulty in establishing their footing as compared to their DUP and the need to be more kinesthetically aware in specific activities, for example using the stairs.

> But in terms of lateral movement and moving side to side, they were a learning challenge because you had to figure out where to place your footing, and again you don't have that spatial awareness underneath, so it's like not spiking yourself or not slashing the side of your leg – which I still do now! [laugh] So, it's just like being very kinaesthetically aware with … your surroundings and your movement patterns, basically. (C4)

One child elaborated on the difficulty to traverse hills owing to the small RSP base and open blade design as compared to a DUP where the hard keel is covered with a plastic/rubber foot covering.

> It's actually pretty difficult to go up hills on a running leg because the blade is kind of like an L shape and … the blade doesn't extend very far past where my socket is aligned. So there's very little surface that actually ends up on the hill since it's slanted, and there's just some hills that are just too steep, I just can't do them because I'll just fall down. So that's kind of hard. Stairs are better! Because they're a flat surface. (C6)

The hard, pointed tip of the blade was another area of concern requiring caution when using the device for certain activities.

> I'm afraid to use my [running] leg at martial arts because I don't want to hurt anyone. (C8)

RSP suspension could also have certain issues. Excessive sweat would lead to discomfort and would occasionally necessitate switching liners or wiping down sweat during and/or after use. Children shared examples in which the loss of suspension was a safety concern.

> Well, sometimes I get really sweaty … [Once] we were playing volleyball and then my legs were super sweaty – so one of them just fell off and then I fell down! (C5)

Subtheme 2: Getting used to it

This subtheme describes children's experience learning how to use their RSP. In general, they found the beginning of the learning journey the most challenging. Parents mentioned how visiting a physiotherapist helped by providing a safe learning environment. When contrasting their RSP learning experience with that of their DUP, some found that learning to use a new DUP had been more difficult. As one child said:

> "It was harder [to learn to use a DUP], but it took less time. Even though I knew how to walk, it was just an issue of [the DUP]- um, being too painful, or building up the endurance to be able to do it. Whereas my running leg, I already had the endurance, but the actual motion was a lot more difficult, I'd say." … "It's not that hard [to learn to run with an RSP], but it's really different from running on a regular leg, you have a spring underneath you … getting your stride right is difficult. It doesn't sound like it'd be that hard but making sure that your [strides] are even, making sure that you're trusting your prosthetic leg enough to put enough weight on it, um, using your arms properly, … there's a lot more that you think about than when you're walking. It's just not. as intuitive as it was learning to um, walk." (C6)

As touched on in Theme 1, maintaining balance with an RSP was a concern for many. This was in part attributed to the posterior attachment of some RSPs.

> I think at first it was a little hard [learning to use an RSP] because … you're not flat footed anymore, you're curved, yeah you've got to balance without being flat, … The balance is definitely different, um, it feels different because there's not as much on the bottom as there is on the other two legs [DUP and swim leg] … my first [RSP], um, the blade was behind it, so I wasn't standing on anything, it's just supported on the back, so it definitely felt weird, because my leg was suspended, basically. (C3)

Finances associated with obtaining an RSP were a consideration for many parents and children. The high cost was discussed as potentially posing a moral obligation in terms of using the RSP.

> Make sure you're going to use it because I mean, these things, they're expensive. I would get the receipt for my- my new legs, especially with the liners and stuff. they're thousands of dollars each and then add those all together, especially if you're double [amputee] or whatever. Definitely make sure you're going to use it. (C3)

Subtheme 3: More planning

This subtheme highlights the additional planning needed in transporting and storing prostheses. Most children mentioned that they carry the RSP with them to school or wherever they plan to use it. Parents mentioned that this was challenging especially as the children grew and the prosthetic components became larger and more difficult to transport. Most chose not to leave their RSP at school either due to a lack of storage or the fear of misplacing the expensive prosthesis.

One parent of a child with bilateral limb loss described their experience of travelling and transporting the DUPs and RSPs.

> Having multiple legs, right? And then having to transport it does carry onto your luggage so, … we need to make sure do we really need the running legs? Will [they] use that? Or will [they] use [their] everyday legs more, so we really have to think ahead of time, you know, what works best … (P5)

Parents discussed the need for additional planning especially when it came to switching between prostheses. One discussed the struggles with their child not wanting to switch between prostheses.

> We sometimes have good days and bad days with putting [their] leg on … when it's comfortable then [they want] to put [their] leg on but on the days when it's not comfortable then it can be a bit of a struggle. So um, you know, I think that's something to sort of take in mind with any of these legs and when you're switching them, sometimes it can be tricky and the child does not want to switch legs. I think as they get older, I think it becomes easier and they recognize the importance of it, but when they're … still kind of young and not necessarily always thinking of the benefits, sometimes just thinking about the immediate moment and what's that feeling like and so we sometimes have struggles and fights about putting legs on. … We go through phases where [they] just don't want to wear them at all. (P8)

Parents also shared their frustration in managing multiple legs with regards to production times and the need to resize the prostheses as the child grows.

> Probably the most frustrating thing is the production time, sometimes it takes over a month to get them, sometimes longer, and- I mean, [they've] gone through growth spurts, you know, [the prosthetist] had to re-cast and re-do and stuff and, I mean basically [the prostheses] are machines and when things go wrong with them, things break that, you know, we've got to be able to fix them with duct tape or get somebody who knows what they're doing to fix them. But I guess … we kind of all have it down to a science now. We don't even think about it half the time, until something breaks. (P7)

> Uh, it's been tricky because each of [the prosthetic legs], because they're cast usually at different times, [they're] outgrowing one but not another so we're kind of constantly getting something adjusted or fixed. (P8)

Discussion

The purpose of this study was to investigate how children use RSPs and the impact of RSP use on sport and physical activity participation. Benefits that children experienced from using RSPs

ranged from being able to run with friends for the first time to unlocking a higher level of performance previously not thought possible. Children and their parents discussed how participating in sports helped to boost their confidence, and this aligns with previous studies [28]. Children found that RSP use was advantageous for sports that involved jumping, such as basketball and gymnastics. However, when children attempted to use their RSPs for other activities or for longer periods of time, they faced various issues often necessitating them to switch back to their DUP.

Children's decision-making regarding which prosthesis to do for a particular activity relied on the functionality and comfort of the prosthesis. A main limitation in the functionality of the RSP was the difficulty to maintain balance when standing still or trying to stop. This was likely due to the curved shape, small base, and inertial properties of the RSP [29]. Similarly, children faced issues performing quick start–stop motions common in many court-based sports. Activities such as kicking a soccer ball also presented occasional problems with the ball becoming stuck in the RSP. Another contributing factor that limited RSP functionality was the difficulty of traversing uneven terrain, such as when engaging in physical activity outdoors. These examples point to some of the challenges of RSP use as well as RSPs' limited versatility to enable a variety of common play and sports activities [30].

While bilateral amputations are typically more challenging to accommodate with prostheses due to the loss of function of both lower limbs, in the case of RSPs, unilateral amputations present a particular challenge. Children with unilateral LLA faced issues with leg length discrepancy since the RSP is typically prescribed to be 5 cm longer than the intact limb to accommodate for the blade deflection during running [31]. Leg length discrepancy can lead to discomfort and back pain limiting the unilateral RSP user from donning their RSP for activities other than running [32]. In contrast, the three children with bilateral LLA reported a preference for using their RSP in non-running physical activities such as walking or playing in the park.

Prosthetic comfort is an important factor influencing user satisfaction and usage [33], and a lack of comfort limited children's RSP wear-time. Excessive sweat in socket liners caused discomfort and posed a safety risk since the RSP can slip off leading to injury to the child or bystanders. Innovations in the design of liners for sport-use, such as gel liners, can potentially address these issues. In addition to sweaty liners, children discussed ill-fitting sockets being a common issue leading to discomfort. These findings regarding prostheses discomfort contradict results from a recent study regarding RSP satisfaction with adult users which found that, in general, users did not experience socket discomfort leading to irritations [34]. The differences between the adult and pediatric opinions emphasize the importance of timely care to accommodate the child's continual growth, especially in the management of multiple prosthetic devices.

Children liked the unique or "cool" look of their RSP even though it lacked the appearance of a biological limb. In contrast, the resemblance of their DUP to a biological limb was often stated as a main advantage with DUP use. The importance of RSP functionality over aesthetic resemblance to biological limbs is consistent with studies on adults [34].

The ideal lower limb prosthesis would closely replicate the functionality of a biological limb without necessitating switching between different prosthetic devices. The development of a multifunctional prosthesis would be advantageous for children to simplify the rehabilitation process especially for those looking to use their RSP for daily active play. As illustrated in the "Every leg serves its purpose" theme, there were instances when the RSP was "too much" and the DUP was "not enough", wherein neither the DUP nor RSP was sufficient to allow the child to complete the activity. Unlike biological limbs, RSPs have a fixed stiffness making their use difficult over different running and jogging speeds [35]. This supports the need for the development of prostheses with broader functionality. Dynamic elastic response prostheses (DERPs) are a potential alternative to RSPs. Similar to RSPs, DERPs are also made from carbon fiber to provide energy return capability; however, they include a heel component which can help the user maintain balance especially during standing [36]. DERPs have also shown promise for use in sports through the evaluation of the start–stop motion [37]. However, additional research is needed to compare functionality among DERPs, DUPs and RSPs, especially in the context of pediatrics.

The data revealed that learning to run with an RSP was generally deemed to be less difficult than learning to walk with a DUP. However, this is likely a reflection of the challenges associated with the rehabilitation of a new amputee and learning to walk with an initial prosthesis, which would typically be a DUP rather than an RSP. An RSP would usually only be prescribed once a child becomes comfortable using a DUP. When using an RSP, children discussed the need to adapt to the feeling of being suspended/unbalanced/unsupported due to the posterior attachment of the RSP [38]. This can be an issue if it leads to the children mistrusting their prosthesis, further worsening the limb asymmetry [39]. While none of the children expressed concerns with the appearance of their RSPs, differences in the shapes of the blade and natural leg can make it harder to have a kinesthetic awareness of the foot, especially due to the small base of the RSP.

Although RSPs enable participation in some sports, they are not necessary for all land-based sports, and in some cases the best option may be no prosthesis at all [40]. Some participants preferred to remove their prosthesis for gymnastics to feel more balanced, playing seated volleyball, wheelchair kin-ball, sledge hockey, or using their DUP or stubbies (foreshortened prostheses used by individuals with bilateral LLA) [41] for certain sports such as soccer, climbing, bicycling, or riding a scooter. Not using a prosthesis can be an important alternative in enabling and promoting participation in sports.

Another important factor is to recognize the additional planning and resources needed to support a child using different prosthetic devices [42]. Storing, transporting, and managing the repairs and adjustments of devices are important considerations. Existing financial barriers and the subjective nature of prosthetic limb prescription [43] are important considerations for understanding who has access to pediatric RSPs. This can include any preconceptions that children and families may have about RSPs. In this study, one child explained what an RSP can be used for, stating, "it's in the name, it's for running". This begs the question of whether the name of the device is limiting the potential breadth of prescription and use. Are some parents, children, and perhaps even clinicians perceiving RSPs to be only suitable for running? Children were inspired to get an RSP either by seeing somebody else use them or by recommendation from their clinicians. Might this be limiting the extent of children who gain access to RSPs? Moreover, the steep financial costs, even with funding support, may result in a sense of moral obligation to ensure that the prostheses are being adequately utilized. Development of a more thorough understanding of RSP prescription barriers and facilitators is warranted.

Limitations

All participants were recruited from the same prosthetic clinic and thus likely lived in the same geographic area and shared at least some urban cultural similarities. There is a need to repeat this research in different urban and rural regions. Also, study participants recruited were all current RSP users which could explain the positive outlook on RSP use since all participants chose to use their devices. This may have resulted in a biased viewpoint given the omission of children who had discontinued RSP use perhaps due to negative experiences or those that chose not to use an RSP at all. Moreover, it is important to recognize that the researchers' roles, experiences, identities, and beliefs impact the research process and outcomes [44]. Another limitation to consider is the absence of member checking (by the youth participants) of the interview data or emerging themes. The decision to omit member checking was based on consideration of the associated philosophical issues related to the epistemology and ontology of qualitative inquiry and the practical issues with respect to conducting and then interpreting the results of member checking [45,46]. In the spirit of co-creation, "member reflection", as described by Smith and McGannon [46], might be a suitable process to consider in future studies as a way of drawing participants together into a joint conversation with the researchers towards a collaborative interpretation of results, addressing any perceived gaps or contradictions in the findings. In addition, the use of content analysis helped to promote trustworthiness since content analysis is more likely to directly reflect the study participants' unique experiences as stated to the researchers [16]. Since interviews were conducted during the COVID-19 pandemic, this impacted the study participants' usual recreational activities and limited their ability to engage in physical activity with their peers. Study participants were encouraged to share their experiences prior to the onset of the global pandemic. It was assumed that the child participants had sufficient memory to provide responses that are representative of their RSP user experience, and there was no outward indication in the interviews of any issues with recall.

Conclusions

This study provides the first insights into how children with LLA use RSPs as well as the positive and negative aspects of RSP use. Study results point to the overall positive impact that RSP use has on children's ability to engage in sports and physical activities. The experiences of some of the children show that RSPs can be used for much more than running. There were negative aspects of RSP use experienced by some children that also need to be considered, and these included balance challenges and discomfort caused by leg length discrepancies and/or ill-fitting sockets that made using the RSP for longer periods difficult. To address the limitations of alternating RSP and DUP use, DERPs could be considered as a multi-functional alternative that would help to limit the need for switching between devices. Parents of children with RSPs experienced the need for extra planning in transporting and storing multiple prostheses and making sure that regular adjustments were made to both the child's RSP and DUP to accommodate physical growth. Future research should focus on investigating RSP use within a broader pediatric sample and implementing creative solutions to prosthetic design. Finally, the development of the future generation of pediatric RSPs should be a collaborative process that supports co-creation with children, families, clinicians, and researchers/engineers to develop prostheses that are safe, reliable, and afford children the opportunity to participate in the sports and other physical activities that interest them.

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