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Systematic Review

Exploring the Unmet Need for Technology to Promote Motor Ability in Children Younger Than 5 Years of Age: A Systematic Review

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KEYWORDS
Child;
Infant;
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Abstract *Objective:* To (1) identify types of technology that promote motor ability in children younger than 5 years of age, (2) report on the type of support these devices provide, and (3) evaluate their potential for use in the community (outside of the laboratory or clinic).
Data Sources: A literature search of PubMed was conducted in February 2019 using specific terms, including child, rehabilitation, movement, and instrumentation.
Study Selection: The search yielded 451 peer-reviewed articles, which were screened by multiple reviewers. Articles that described the use of devices for the purpose of motor rehabilitation and/or assistance (regardless of device type or body part targeted) in the age range of 0-5 years were eligible for inclusion.
Data Extraction: In conformity with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, final stage data extraction consisted of full text readings where each article was reviewed twice by 3 independent reviewers.
Data Synthesis: About half of the devices available (46%) for children younger than 5 years of age are orthotics and corrective casting devices. There are more facilitative (ie, power mobility devices) than inhibitive (ie, casting) technologies being used. Approximately 60% of the devices are designed for use by a single body part. Walking is the most common motor skill addressed. Although most of the devices were used to some degree outside of the laboratory or clinic, most of the devices available are considered investigative and are not available for commercial purchase.

List of abbreviations: DIY, Do-It-Yourself.
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Conclusions: Many types of pediatric devices to assist movement exist, but the current scope of employed devices is limited. There is a need for developing technology that allows for, if not supports, high-dosage, early, and variable motor practice that can take place in community settings.

The use of technology has become an important aspect of rehabilitation in recent decades. Although various types of technology exist, most devices can be broadly defined as assistive and/or rehabilitative. Assistive technology refers to tools that aid individuals with or without injury in performing everyday tasks (eg, walkers, wheelchairs, prosthetic devices), whereas rehabilitative technology refers to tools that are used to "help people recover or improve function after injury or illness" (eg, treadmills, robotic devices).[1(para 1)] Although advances in both assistive and rehabilitative technology are often pursued and reported in adult rehabilitation, it seems that this is not the case in pediatric rehabilitation.

There is a high demand for both types of technology applicable to intervention and milestone development in pediatric populations in the United States. Pediatric brain and birth injuries are highly prevalent and can significantly affect motor function later in life. It is estimated that birth defects affect 1 in every 33 newborns each year[2] and nearly 1 in 6 children have a developmental disability.[3] The unmet need for available mobility aids, according to the National Survey of Children with Special Health Care Needs, has only been increasing throughout the years, with the highest need being reported in children aged 3-5 years.[4,5] A national call for technology used for diagnosis, intervention, and outcome assessment of children with brain injury and motor disability, issued by the American Physical Therapy Association, emphasizes the need for technological innovation in this population.[6,7] Various possible factors contributing to these statistics may be considered.

Certain population characteristics, such as the presence of rapid developmental and growth changes and the nature of complex activities children are engaged into, make the design of pediatric devices and their application in this population challenging. Most of the motor skills (eg, reaching, sitting, standing, walking, climbing, etc) typically emerge in the first 2 years of life. Attainment and maturation of these early motor skills allow young children to interact with people, objects, and their environment in different ways[8-15] and set the foundation on which other skills are later developed.[16] Although developmental changes *effortlessly* take place in typical development, in children with disabilities, this process may be hindered and/or delayed. Cascading effects stemming from these delays/deficits in motor abilities may have lasting effects in other developmental areas and quality of life.[17-20] For example, children diagnosed with autism, who often demonstrate difficulty with postural control, do not demonstrate the same dramatic increase in vocabulary abilities at the onset of walking as their typically developing peers.[21] Assistive and rehabilitative technology designed for use by children in this age range should support early, variable motor practice and allow for independence to minimize this cascade of effects.

Another possible factor contributing to the need for advances in pediatric motor devices is the limited capacity and/or access of devices that can offer high-dose use outside of the laboratory. Assistive devices that move with the child can translate to their use in the community, maximizing the potential for performing physical activities and gaining a plethora of experiences and learning opportunities, all thought to be important for inducing meaningful behavioral and brain changes.[22-25] High-dose usage of such devices may also maximize the potential for rehabilitative effects.[25] Consequently, to be able to provide the best opportunity for children with motor impairments to get the maximal outcomes, technology should allow for, if not support, high-dosage, early, and variable motor practice that can take place in the community.

The goal of this systematic review was to examine the current state of pediatric assistive and rehabilitative technology and assess their ability to support high-dosage, early, and variable motor practice in nonclinical settings. This would provide an insight on the needs that are being met and the associated challenges, which can both inform future device design and development for this population. More specifically, we aimed to (1) identify devices to support movement in children younger than 5 years, (2) report on the type of support these devices provide, and (3) evaluate their potential for use in the community (outside of laboratory or clinic).

Methods

Search strategy

A systematic literature review of peer-reviewed journal articles on pediatric assistive and rehabilitative technology was conducted in PubMed. The search included articles from inception to February 2019 using the following key terms: ("Child, Preschool"[Mesh] OR "Infant"[Mesh]) AND ("Physical Therapy Modalities"[Mesh] OR "Rehabilitation"[Mesh] OR "rehabilitation"[Subheading]) AND ("Movement"[Mesh]OR "Mobility Limitation"[Mesh]) AND ("Technology"[Mesh] OR "Equipment and Supplies"[Mesh] OR "instrumentation" [Subheading]). The review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[26,27]

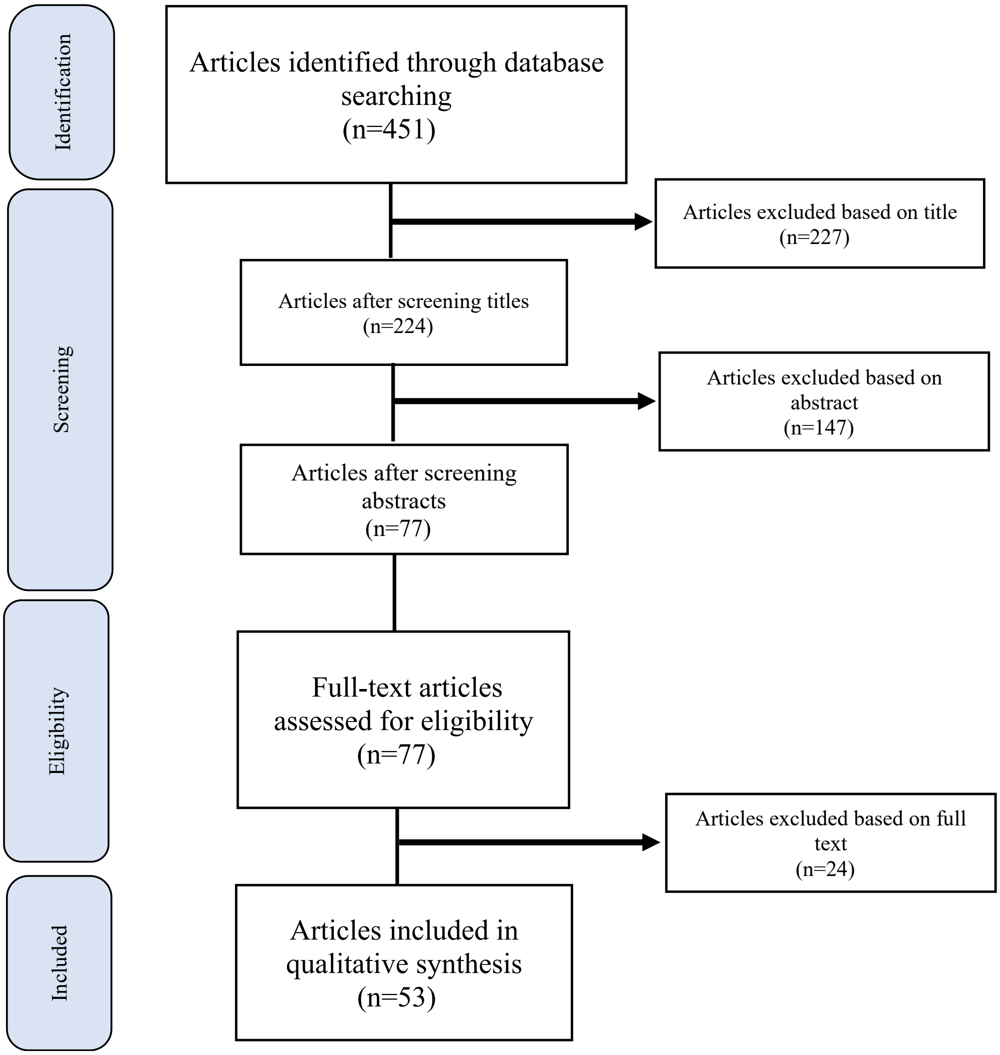

Fig 1 PRISMA flow chart.

Inclusion criteria

Articles were included if (1) they were peer-reviewed and published in English; (2) they described technologies for motor rehabilitation and/or assistance (regardless of device type or body part targeted); (3) their population focus was children 0-5 years of age (regardless of diagnosis or number of participants).

Study selection

The initial search resulted in 451 articles. After 5 reviewers screened the titles of all articles, 227 were excluded resulting in 224 articles. After the review of abstracts of these articles by 2 reviewers, 147 articles were excluded for not meeting the inclusion criteria, leaving 77 articles for full-text review. After full-text review by 2 reviewers, an additional 24 articles were ultimately excluded for not meeting the inclusion criteria, resulting in 53 articles considered in this systematic review (fig 1). Disagreements of inclusion or exclusion during title screening, abstract, and full-text reviews were resolved through discussion.

Data extraction

During data extraction, 3 independent reviewers revisited each full text twice and gathered data on (1) author or year, (2) device type, (3) targeted body part, (4) type of support, (5) if the technology was commercially available or investigative, (6) motor skill targeted by the device, (7) application in the community, (8) age of participants, (9) participants' diagnosis, and (10) number of participants (table 1). Information on targeted body part, participants' diagnosis, age of participants, number of participants, and application in the community was extracted directly from the articles. Information on device type, type of support, motor skill targeted, and investigative or commercial status required the reviewers' interpretation and were extracted utilizing operational criteria. Below are descriptions for each category.

Device type

Each device was classified as one of the following subcategories: *Orthotics*, *Treadmill*, *Casting*, *Rideable*, or *Other*. *Orthotics* included any sort of orthotic device

Table 1 Summary table of the systematic review results on technology available for young children with motor deficits

Author	Device Type	Targeted Body Part	Type of Support	Investigative/ Commercial	Motor Skill	Application in the Community	Age	Diagnosis	No. of Participants
Balogh et al[28]	Rideable	Multiple	Facilitative	Investigative	Not specified	Yes	0-2	Limb deficiency	1
Douglas and Ryan[29]	Rideable	Arm	Facilitative	Investigative	Not specified	Yes	3-5	C4 Injury	1
Huang and Chen[30]	Rideable	Arm	Facilitative	Commercial	Not specified	Yes	Both	Impairments preventing functional independent mobility	11-50
Jones et al[31]	Rideable	Arm	Facilitative	Investigative	Not specified	Yes	Both	Multiple	11-50
Kenyon et al[32]	Rideable	Arm	Facilitative	Investigative	Not specified	No	Both	Cerebral palsy	2-10
Larin et al[33]	Rideable	Torso	Facilitative	Commercial	Not specified	Yes	Both	Cerebral palsy	2-10
Logan et al[34]	Rideable	Arm	Facilitative	Investigative	Reaching	Yes	0-2	Down syndrome	1
Logan et al[35]	Rideable	Arm	Facilitative	Investigative	Standing	Yes	3-5	Clubfoot	11-50
Logan et al[36]	Rideable	Arm	Facilitative	Investigative	Not specified	Yes	0-2	Multiple	2-10
Mockler et al[37]	Rideable	Arm	Facilitative	Commercial	Not specified	Yes	Both	Multiple	11-50
Paleg et al[38]	Rideable	Multiple	Facilitative	Commercial	Walking	No	3-5	Cerebral palsy	1
Ragonesi et al[39]	Rideable	Arm	Facilitative	Investigative	Not specified	Yes	3-5	Cerebral palsy	1
Ragonesi and Galloway[40]	Rideable	Arm	Facilitative	Commercial	Reaching	Yes	0-2	Cerebral palsy	1
Schoepflin et al[41]	Rideable	Arm	Facilitative	Investigative	Not specified	No	0-2	Cerebral palsy	2-10
Schoepflin et al[42]	Rideable	Multiple	Facilitative	Investigative	Walking	No	0-2	Cerebral palsy	2-10
Altizer et al[43]	Orthotics	Lower body	Both	Commercial	Walking	Yes	0-2	Spinal cord injury	1
Buccieri[44]	Orthotics	Lower body	Both	Commercial	Multiple	Yes	3-5	Hyperpronation	1
Currie and Mendiola[45]	Orthotics	Hand	Both	Investigative	Reaching	Yes	Both	Cerebral palsy	2-10
Durlacher et al[46]	Orthotics	Arm	Both	Investigative	Reaching	Yes	0-2	Brachial plexus injury	0
Embrey et al[47]	Orthotics	Lower body	Both	Investigative	Walking	Yes	3-5	Cerebral palsy	1
Granata et al[48]	Orthotics	Lower body	Both	Investigative	Multiple	Yes	Both	Spinal muscular atrophy	2-10
Harris and Riffle[49]	Orthotics	Lower body	Both	Investigative	Standing	Yes	3-5	Cerebral palsy	1
Middleton et al[50]	Orthotics	Lower body	Both	Investigative	Walking	Yes	3-5	Cerebral palsy	1
Rosenthal[51]	Orthotics	Lower body	Both	Investigative	Multiple	Not specified	Both	Cerebral palsy	0
Ross and Krilov[52]	Orthotics	Lower body	Both	Investigative	Walking	No	3-5	Burn victim with foot-ankle contractures	1
Wilson et al[53]	Orthotics	Lower body	Both	Investigative	Standing	Yes	3-5	Cerebral palsy	11-50
Cottalorda et al[54]	Casting	Lower body	Inhibitive	Investigative	Walking	Yes	3-5	Cerebral palsy	11-50
El-Hawary et al[55]	Casting	Multiple	Inhibitive	Investigative	Walking	Yes	Both	Clubfoot	50+
Evans et al[56]	Casting	Lower body	Inhibitive	Investigative	Walking	Yes	Both	Clubfoot	50+

Faulks and Richards[57]	Casting	Multiple	Inhibitive	Investigative	Walking	Yes	Both	Clubfoot	0
Gottschalk et al[58]	Casting	Multiple	Inhibitive	Investigative	Walking	Yes	Both	Clubfoot	11-50
Jeans et al[59]	Casting	Multiple	Inhibitive	Investigative	Walking	Yes	3-5	Clubfoot	50+
Jeans and Karol[60]	Casting	Multiple	Inhibitive	Investigative	Walking	Yes	0-2	Clubfoot	50+
Law et al[61]	Casting	Arm	Inhibitive	Investigative	Reaching	Yes	Both	Cerebral palsy	11-50
Panjavi et al[62]	Casting	Lower body	Inhibitive	Investigative	Not specified	Yes	0-2	Clubfoot	50+
Sanghvi and Mittal[63]	Casting	Lower body	Inhibitive	Investigative	Walking	Yes	0-2	Clubfoot	11-50
Sinclair et al[64]	Casting	Lower body	Inhibitive	Investigative	Walking	Yes	3-5	Clubfoot	11-50
van Bosse et al[65]	Casting	Lower body	Inhibitive	Investigative	Not specified	Yes	Both	Clubfoot	2-10
Watt et al[66]	Casting	Multiple	Inhibitive	Commercial	Walking	Yes	Both	Cerebral palsy	11-50
Behrman et al[67]	Treadmill	Torso+lower body	Facilitative	Investigative	Walking	No	3-5	Spinal cord injury	1
Bodkin et al[68]	Treadmill	Torso+lower body	Facilitative	Investigative	Walking	Yes	0-2	Grade III intraventricular hemorrhage	1
Looper and Ulrich[69]	Treadmill	Torso+lower body	Both	Investigative	Multiple	Yes	0-2	Down syndrome	11-50
Looper and Ulrich[70]	Treadmill	Torso+lower body	Both	Investigative	Multiple	Yes	0-2	Down syndrome	11-50
Moerchen et al[71]	Treadmill	Torso+lower body	Facilitative	Investigative	Walking	Yes	0-2	Spina bifida	1
Pantall et al[72]	Treadmill	Torso+lower body	Facilitative	Investigative	Walking	Yes	0-2	Spina bifida	11-50
Teulier et al[73]	Treadmill	Torso+lower body	Facilitative	Commercial	Walking	Yes	0-2	Spina bifida	11-50
Ulrich et al[74]	Treadmill	Torso+lower body	Facilitative	Commercial	Walking	Yes	0-2	Down syndrome	11-50
Babik et al[75]	Other	Arm	Facilitative	Investigative	Reaching	Yes	0-2	Arthrogryposis	1
Fergus[76]	Other	Multiple	Facilitative	Commercial	Walking	Yes	3-5	Cerebral palsy	1
Kerem et al[77]	Other	Multiple	Inhibitive	Commercial	Multiple	No	3-5	Cerebral palsy	11-50
Kokkoni et al[78]	Other	Torso+lower body	Both	Investigative	Multiple	Yes	3-5	Spina bifida	1
Öhman[79]	Other	Neck	Inhibitive	Investigative	Neck strength	No	0-2	Multiple	11-50
Stallard et al[80]	Other	Torso+lower body	Facilitative	Commercial	Walking	Not specified	0-2	-	0

(eg, *ankle foot orthosis*) whereas any study that used treadmills was classified as *Treadmill*. Corrective casting techniques were classified as *Casting* (eg, French and Ponseti methods). Any device that a child could ride on and control was classified as *Rideable* (eg, powered wheelchairs, modified ride on cars). Finally, any device that could not be classified as one of the 4 aforementioned categories was classified as *Other* (eg body weight support systems, exoskeletons, pressure splints).

Targeted body part

The body parts that were involved or had a direct effect from use of the technology were examined and placed into the following categories: *Lower body*, *Torso*, *Neck*, *Arm*, *Hand*, and *Multiple*. A combined category *Torso+lower body* was added to reflect the body parts that were involved or had a direct effect from combining the primary technology with secondary technology or method in some of the studies (ie, treadmill + body weight support).

Type of support

Each device was classified as *Inhibitive*, *Facilitative*, or *Both* based on the type of support they provide to the user. *Inhibitive* devices were defined as those that prohibit a certain range of motion (eg, an orthosis), and *Facilitative* devices as those that aid the user in performing a specific movement (eg, a walker). *Both* denoted the dual role of a device.

Commercialization status

Technology used was also classified as either *Investigative* or *Commercial*. Any commercially available technology that could reasonably be purchased by the family was considered *Commercial* and all other technology was considered *Investigative*.

Motor skill targeted

The motor skill targeted by the technology used was also interpreted. Categories included *Neck strength*, *Sitting*, *Standing*, *Crawling*, *Walking*, and *Reaching*. Devices that contribute to changes in multiple motor skills were classified as *Multiple*, whereas *Not Specified* was used to classify devices developed solely to increase independent mobility (ie, power mobility device) as well as papers that did not examine changes in a specific motor skill (ie, examined range of motion).

Application in the community

We reported on whether the device was used outside of the laboratory or clinic during the study (*Yes*/*No*).

Age of participants

Data on the participants' age were examined and split into 3 categories: *0-2* for participants aged 24 months or younger; *3-5* for participants between 25 months and 5 years of age; and *Both* for inclusion of participants from both categories.

Participants' diagnosis

Data on the diagnoses of the participants in the studies were reported; if children with multiple diagnoses were included in a study, the category used for this article was *Multiple*.

Number of participants

Data on the number of participants potentially involved in each study were examined and reported in 5 categories: *Zero*, *One*, *2-10*, *11-50*, *50+*. Articles reporting on studies where no children participated and single-case designs or reports were not excluded because they might offer information on recent technology development.

Results

To address the objectives of this review, the percentage of papers that demonstrated each subcategory was calculated. To calculate the percentages, the total from each subcategory was divided by the total number of papers (53).

Device type

The most prominent device category was *Rideable*, which represented 28% of papers.[28-42] Twenty-one percent of papers involved *Orthotics*,[43-53] whereas 25% involved *Casting* methods.[54-66] Finally, 15% and 11% of papers used *Treadmill*[67-74] and *Other* types of technology,[75-80] respectively (fig 2A).

Targeted body part

The *Lower body* was targeted the most (28%),[43,44,46-54,56,62-65] followed by the *Arm*[29-32,34-37,39-41,46,61,75] and *Multiple*[28,38,42,55,57-60,66,76,77] which were targeted by the device in 26% and 21% of papers, respectively. Approximately, 19% of the technology targeted the *Torso+lower body*.[67-74,78,80] The remaining technology (6% of the papers) targeted the *Neck*,[79] *Torso*,[33] and *Hand* (fig 2B).[45]

Type of support

Twenty-eight percent of devices were considered *Inhibitive*,[54-66,77,79] whereas 45% were classified as *Facilitative*.[28-42,67,68,71-76,80] Twenty-seven percent of the technology was considered to provide both[43-53,69,70,78] facilitative and inhibitive support, and therefore was classified as *Both* (fig 2C).

Commercialization status

Of the 53 papers, 75% used technology that was classified as *Investigative*,[28,29,31,32,34-36,39,41,42,45-65,67-72,75,78,79] and 25% of the papers used technology that was categorized as *Commercial* (fig 2D).[30,33,37,38,40,44,43,66,73,74,76,77,80]

Targeted motor skill

The most prevalent motor skill targeted for improvement was *Walking*. Technology aimed at improving *Walking* accounted for 45% of the papers.[38,42,43,47,50,52,54-60,63,64,66-68,71-74,76,80] After walking, *Reaching* and *Standing* accounted for 11%[34,40,45,46,61,75] and 6%,[35,49,53] respectively. *Neck* strength was targeted by 2% of the technology.[79] Finally, 13% of the technology targeted *Multiple* motor skills,[44,48,51,69,70,77,78] whereas 23% of the technology did not target a specific

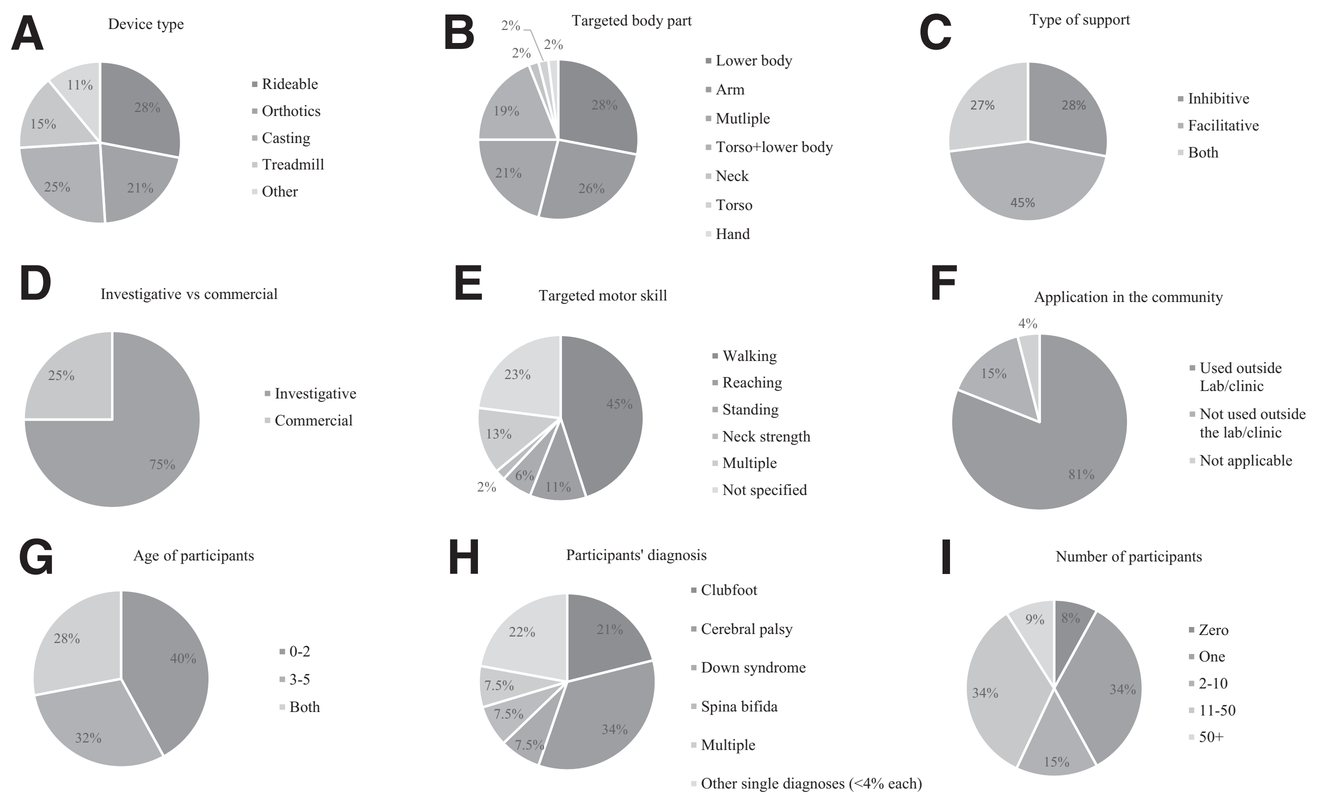

Fig 2 Pie charts display the results for (A) device type, (B) targeted body part, (C) type of support, (D) investigative versus commercial, (E) targeted motor skill, (F) application in the community, (G) age of participants, (H) participants' diagnosis, and (I) number of participants.

motor skill.[28-33,36,37,39,41,62,65] None of the papers solely targeted *Sitting* or *Crawling* (fig 2E).

Application in the community

Eighty-one percent of the studies used their technology outside of the laboratory or clinic,[28-31,33-37,39,40,43-50,53-66,68-76,78] whereas 15% did not use the technology outside the laboratory or clinic within the study.[32,38,41,42,52,67,77,79] Although there was mention of using the technology in a natural environment, 4% of the studies were technical notes that did not explicitly examine the use of the technology inside or outside of the laboratory or clinic (fig 2F).[51,80]

Age of participants

Forty percent of the papers only examined participants that were categorized as *0-2*,[28,34,36,40-43,46,60,62,63,68-75,79,80] whereas 32% examined participants that fell into the *3-5* category.[29,35,38,39,44,47,49,50,52-54,59,64,67,76-78] The remaining 28% included participants in both age groups and therefore were classified as *Both* (fig 2G).[30-33,37,45,48,51,55-58,61,65,66]

Participants' diagnosis

The most prevalent diagnosis of the 53 papers analyzed was *cerebral palsy*, which accounted for 34% of the papers.[32,33,38-42,45,47,49-51,53,54,61,66,76,77] *Clubfoot* followed and accounted for the participants' diagnosis in 21% of the papers.[35,55-60,62-65] *Down syndrome*[34,69,70,74] and *spina bifida*[71-73,78] each accounted for the diagnoses in 7.5% of papers. All the other single diagnosis studies accounted for <4%, respectively.[28-30,43,44,46,48,52,67,68,75] Studies categorized as *Multiple*[31,36,37,79] accounted for 7.5% of the studies and included the following diagnoses: achondroplastic dwarfism, arthrogryposis, and congenital myopathy, Dandy-Walker syndrome, hydrocephalus, myotubular myopathy, progeria, tetraphocomelia, cortical vision impairment, microcephaly, strabismus, congenital muscular torticollis, spinal muscular atrophy, and muscular imbalance in the lateral flexors of the neck (fig 2H).

Number of participants

Most of the studies used a case study design (*1;* 34%)[28,29,34,38-40,43,44,47,49,50,52,67,68,71,75,76] or included a moderate sample size (*11-50;* 34% of papers).[30,31,35,37,53,54,58,61,63,64,66,69,70,72-74,77,79] *Zero* participants[46,51,57,80] were included in 8% of the papers, whereas *50+* participants[55,56,59,60,62] and *2-10* participants[32,33,36,41,42,45,48,65] contributed to 9% and 15% of the papers, respectively (fig 2I).

Discussion

Providing children with motor impairments opportunities for early, variable, and high-dosage mobility, through the use of technology, is essential to their global development.

Results from this systematic review revealed the existence of a variety of technology solutions for early motor impairments, albeit a number of factors should be taken into account regarding these solutions. Opportunities for future technology development for young children are discussed.

Types of technology for children younger than 5 years of age

Many types of technology to assist movement in pediatric populations exist. However, the current scope of employed technology for motor skill development in children younger than 5 years of age remains limited. About half of the technology available for this young population (46%) are orthotic[43-53] and casting devices.[54-66] In addition, more devices (45%) are facilitative than inhibitive. There are advantages and disadvantages to each type of support these devices provide.

Inhibitive devices are often used to inhibit specific movements to aid in structural or muscular changes. More specifically, 86% of the inhibitive technologies in this review are structural change devices (ie, casting)[54-66] that allow for the correction of anatomical impairments, neuromuscular resetting, and correction for poor motor control capabilities. These, however, also allow for limited movement variability, which may affect the learning process. Humans are redundant systems in that movement can be completed in an infinite number of ways (ie, changes in muscles, joint angles, etc) which allows for movements to demonstrate both flexibility and stability.[81] Variability is an integral component to the development of motor skills[8,82,83]; nevertheless, too much variability can also be detrimental.[8] One potential next step for technology research is to examine the optimization of variability allowed by a device.[84] Soft casting may be a good solution for achieving the structural change goals of casting while allowing for some variability that might aid in the learning process. Soft materials are increasingly being used in medical applications, including wearable devices for adult rehabilitation and assistance.[85] Such materials also offer selection of variable assistance for orthotic devices incorporating multiple degrees of freedom and allowing for freezing and freeing those degrees of freedom to accomplish motor goals.[84]

Conversely, facilitative devices are designed to promote movement. Many of the facilitative devices (63%) used in the reviewed literature were Rideable.[28-42] Rideable devices add propulsion, and thus are successful in promoting mobility, which increases the children's depth perception and understanding of the relation of self with other objects in space.[17,86,87] However, these devices do not directly address locomotor skill development. Only 33% of the rideable devices targeted attainment of other motor skills, such as reaching,[34,40] standing,[35] and walking.[38,42] Future research should expand on facilitative devices by developing smart, context adaptive technology that supports locomotor training, while simultaneously allowing for self-produced mobility and environmental exploration. For example, the development of technology that uses kicking, early stepping, and/or crawling to control the device would allow for early training on facilitating leg movements that may contribute to an earlier walking onset.[88] In addition, this type of devices would support task-specific repetitive training, which is essential in motor learning.[89]

The rate and type of motor learning often differ among pediatric populations with motor disabilities, and thus, devices should be able to address a range of motor issues. This review revealed that current devices were tested and used by children with very specific types of developmental disability. More than 50% of the papers examined the use of devices by young children with cerebral palsy[32,33,38-42,45,47,49,50,51,53,54,61,66,76,77] and clubfoot,[35,55-60,62-65] and only 15% by children with Down syndrome[34,69,70,74] and spina bifida.[71-73,78] An opportunity exists to develop technology that aims to address the needs of other less common developmental disabilities or that can be used by children with various developmental disabilities that share motor issues.

Types of motor abilities current devices address

Although there is a variety of devices available (ie, casting, orthotics, treadmills), almost half of the devices being used in this pediatric population are aimed at improving walking abilities (45%).[38,42,43,47,50,52,54-60,63,64,66-68,71-74,76,80] In addition, most devices (60%) specifically targeted a single part of the body, either upper[29,30-37,39-41,45,46,61,75,79] or lower body,[43,44,47-54,56,62-65] and only approximately one-third of the papers described devices that solely focused on the upper body.[29-37,39-41,45,46,61,75,79] Consequently, the focus in this age range is largely on leg locomotion disregarding the need for training of other complex motor skills where the simultaneous use and coordination of all limbs is required (eg, crawling).

Walking is a major motor milestone that has been linked to other developmental domains,[10,12,90,91] but the attainment of motor skills that emerge prior to walking is also crucial for child development. For instance, motor impairments in the upper body can be detrimental to a young child's ability to achieve fundamental motor skills, such as reaching and crawling. Reaching for and manually manipulating objects allows children to learn about the properties of objects and is linked to other areas of development, such as language.[92,93] Crawling is one of the earliest forms of self-produced movement that is important for environmental exploration, parental interactions, and global development.[11,17] Consequently, as experience with other motor skills is important for independent mobility and overall development, there is a need to expand devices that support more skills than walking.

Another fundamental ability is that of transitioning between different motor tasks. Transitions are an integral part of the daily life of young children and important for facilitating perceptual-motor skill development. For example, sit-to-stand transitions provide infants with possibilities for action in the environment.[94] Similarly, other transitional skills, such as rotating to sit, squatting down to the floor, pulling to standing, and squatting to stand, are strongly correlated with locomotor skills.[95] In this review, only 3 studies assessed devices for their ability to address such transitions.[34,53,78] Orthotics such as hinged ankle foot orthosis and body suspension systems seem to be beneficial for improving this ability.[53,78] Nevertheless, there is a need to develop and assess more types of technology for supporting transitional skill development.

Of great interest in this review was to examine if there is technology that addresses skill development very early in life. The onset of fundamental motor skills typically emerges during the child's first 2 years of life; therefore, the use of technology by infants and toddlers would be extremely beneficial. This review showed that only 40% of the studies examined assistive and rehabilitative devices in children younger than 2 years.[28,34,36,40-43,46,60,62,63,68-75,79,80] These devices were primarily rideables[28,34,36,40-42] and treadmills,[68-74] with only 2 of the devices targeting multiple motor skills.[69,70] Development of technology that can aid in the concurrent attainment of several motor skills in this age group should be a focused effort. A device, for example, that simultaneously assists infants in reaching and sitting would increase the affordances for exploration leading to the advancement of overall development.[9,20,96-98]

Community device integration

Use of devices in a community setting affords young children and their families' natural access to high-dosage training. Early intervention programs that use high-dosage training lead to greater outcomes.[25] In this review, although most of the devices (81%) were used outside the laboratory or clinic at some capacity,[28-31,33-37,39,40,43-50,53-66,68-76,78] many of the devices currently being tested are for investigative use.[28,29,31,32,34-36,39,41,42,45-65,67-72,75,78,79] In fact, only a quarter of the devices were commercially available.[30,33,37,38,40,43,44,66,73,74,76,77,80] This may be due to the lengthy process of commercialization, which requires safety control testing by the companies. During that time, however, children with disabilities miss experiences due to their motor limitations. In the past few years, a wave of technological innovation has emerged that could potentially address this issue.

Commercialization is not the only way to give access to families in need of assistive technology. Do-It-Yourself (DIY) technologies are lately on the rise due to affordable access to hardware and software tools, the use of which was for years the sole privilege of professional engineers. Open-source instructions created by professionals and low-cost 3D printers can now make the development of hand prostheses and foot braces feasible.[99,100] Use of simple materials and garage tools allows parents to create devices to promote their children's mobility, by modifying affordable ride-on toy cars and sewing wearables that provide arm movement support.[34-36,39,40,101,102] Providing more DIY technological solutions to families and clinicians can translate to increased mobility in the community.

If technology is to be made readily available, regardless of the choice of the commercialization or DIY route, it needs to first be tested with human participants. Opportunities related to sample size are available, which may reduce the time in development of the device needed to reach its user but not the quality of the technology. This point of discussion emerged as this review revealed that the most of the devices (two-thirds of research) were tested and reported in a case study design.[28,29,34,38-40,43,44,47,49,50,52,67,68,71,75,76,78] Although there are benefits to conducting case studies, such as examining the feasibility of newly developed technology, another possible design may be beneficial, which uses a case series model of 3-5 participants. Case series designs may provide additional insight into the feasibility and outcomes associated with new technology. In addition, depending on the study, a case series model may be a more cost-effective design to gather valuable information regarding the technology. Furthermore, utilizing a single case design (or n-of-1 designs) may also provide valuable longitudinal information regarding the relation between the use of these technologies and the developmental outcomes in young children.[103]

Study limitations

There are several strengths and limitations to this review. This is the first systematic review of the current state of pediatric assistive and rehabilitative technology for very young children. To progress the field, researchers, engineers, and clinicians should understand the reasons for the current state; this review provides an insight on the needs that are specific to the young population that are not currently being met and that shoud be considered for future device development. Second, this review included a broad spectrum of devices, motor skills targeted, and sample sizes. By not restricting the search terms regarding these aspects, this review captured a more comprehensive understanding of the assistive and rehabilitative devices that have been developed for the pediatric population. One limitation of this study is the lack of publication date restriction. Although including the broad spectrum of devices that have ever been developed is a strength of this review, the results of the search may have been different if only papers published in the last decade had been included. Another limitation is that we conducted our search using only 1 database which is a medical library. Additional assistive and rehabilitative motor devices for our targeted population may have been developed and reported in a library targeted to technology and engineering audiences (eg, IEEE Explore) that were not captured in our search.

Conclusions

Overall, there is currently evidence that devices can lead to an increase in motor abilities in young children, but there are opportunities to improve the scope of the devices available. These opportunities include a lack of diversity in targeted populations examined as well as the developmental skills targeted and limited devices that are commercially available for high dosage use in the home. To progress the field, further development of technology is needed to address these gaps. Future rehabilitative technology efforts might include development of soft robotics that allows for variability of movement and power-assistive devices that can be used outside of the clinic, as well as new devices aimed to improve mobility in developmental skills other than walking and for less common motor impairments.

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