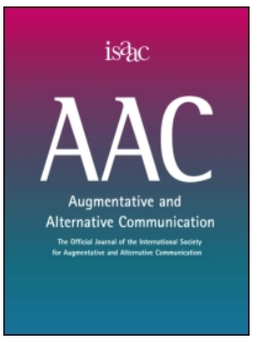

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Challenges and opportunities in augmentative and alternative communication: Research and technology development to enhance communication and participation for individuals with complex communication needs

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NOTE

Challenges and opportunities in augmentative and alternative communication: Research and technology development to enhance communication and participation for individuals with complex communication needs

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ABSTRACT

The field of augmentative and alternative communication (AAC) has witnessed significant changes since its inception. AAC services are now considered for a much greater number of individuals with complex communication needs and there are many more AAC options available as communication supports, including a proliferation of technologies. The scope and options for communication within society have increased substantially to include a wide array of digital and social media. Individuals with complex communication needs have increased expectations for participation and engagement across a full range of environments—education, employment, family, healthcare, and community living. Despite these advances, there remain critical challenges that must be addressed. This paper discusses key advances in the AAC field, delineates challenges, and discusses future directions to address these challenges, specifically as they relate to research and development to enhance AAC interventions and technologies for individuals with complex communication needs and their families.

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Introduction

Since clinicians and researchers first started to explore augmentative and alternative communication (AAC) strategies and techniques, there have been significant advances in the field; however, there remain key challenges that must be addressed to ensure that *all* individuals, including those with the most complex needs, have access to the fundamental human right of communication (Brady et al., 2016). In this paper, we highlight important advances in the AAC field, current challenges, and future directions in research and technology development to address these challenges. Many of these advances, challenges, and future directions are then explored in further detail in the papers that comprise the rest of this special issue of *Augmentative and Alternative Communication*, which focuses on the state of the science and future research priorities in the following areas: (a) new and emerging technologies to improve access for individuals with severe motor impairments (Fager, Fried-Oken, Jakobs, & Beukelman, 2019); (b) effective research-based AAC interface displays for children and adults with developmental or acquired disabilities (Light, Wilkinson, Thiessen, Beukelman, & Fager, 2019); (c) new and emerging AAC technology supports for children with complex communication needs and their communication partners (Light, McNaughton, & Caron, 2019); and (d) strategies and techniques to build capacity in AAC to support participation by people with complex communication needs (McNaughton et al., 2019).

This issue of *AAC* was spearheaded by the Rehabilitation Engineering Research Center on Augmentative and Alternative Communication (The RERC on AAC)[1], which is funded by the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) in the US. It should be noted that AAC includes a wide range of unaided and aided strategies and techniques to support the communication and participation of individuals with complex communication needs. This issue has a specific focus on research and development related primarily (although not exclusively) to high-technology AAC supports; however, many of the issues discussed are relevant to other AAC supports as well. Furthermore, it is important to emphasize that AAC technologies are only one important factor in AAC intervention; they are by no means the only factor. Intervention is also essential to build an individual's linguistic, operational, social, and strategic skills and to teach communication partners effective interaction strategies.

[1]The RERC on AAC is a research, development, training, and dissemination centre (http://rerc-aac.org) with the mission to advance knowledge, improve technology solutions, increase evidence-based practice, and build capacity in AAC to improve outcomes for individuals who have complex communication needs and require AAC.

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Advances in the AAC field

Since its inception, the AAC field has experienced significant changes that have impacted profoundly the lives of individuals with complex communication needs, their families, and caregivers, as well as the professionals that provide services. These advances include the (a) increased provision of AAC services; (b) proliferation of technologies as communication supports; (c) increased scope and options for communication; and (d) increased expectations for participation and engagement.

Increased provision of AAC services

With medical advances, improved survival rates, greater longevity, and increased incidence of some disabilities (e.g., autism spectrum disorder), there are greater numbers of individuals worldwide who have complex communication needs and who would benefit from AAC (Light & McNaughton, 2012a). There is now a robust body of research demonstrating the positive effects of AAC for individuals with complex communication needs resulting from a wide range of developmental, acquired, degenerative, and temporary conditions, across a wide range of ages (e.g., Beukelman, Fager, & Nordness, 2011; Beukelman, Hux, Dietz, McKelvey, & Weissling, 2015; Fried-Oken, Mooney, & Peters, 2015; Ganz et al., 2011; Ganz & Simpson, 2018; Holyfield, Drager, Kremkow, & Light, 2017; Kasari et al., 2014; Romski et al., 2010; Romski, Sevcik, Barton-Hulsey, & Whitmore, 2015; Simmons-Mackie, King, & Beukelman, 2013; Snell et al., 2010). Increased awareness and acceptance of AAC have resulted in its successful integration into more traditional interventions for some populations including, for example, children with autism spectrum disorder or Down syndrome (e.g., Brady, 2008; Ganz & Simpson, 2018; Kasari et al., 2014) and adults with acquired conditions, including those with severe chronic aphasia, primary progressive aphasia, and dementia (e.g., Lanzi, Burshnic, & Bourgeois, 2017; Mooney, Bedrick, Noethe, Spaulding, & Fried-Oken, 2018; Simmons-Mackie et al., 2013). In recent years, AAC services have been extended to address patient-provider care (e.g., Blackstone, Beukelman, & Yorkston, 2015; Blackstone & Pressman, 2016) as well as the needs of those with temporary conditions such as those in intensive care settings (e.g., Costello, Patak, & Pritchard, 2010). Furthermore, with ongoing global advocacy, AAC services have been extended to meet the needs of individuals in low resource countries (e.g., Bornman, 2016; Muttiah, McNaughton, & Drager, 2016). With more individuals with complex communication needs, families, and practitioners recognizing the positive effects of AAC, a greater number and broader range of individuals are seeking and receiving AAC services than ever before.

Proliferation of technologies as communication supports

The past decade has also witnessed the rapid proliferation of technologies (especially mobile technologies) in society, not just in high-resource countries but also low-resource areas (Bornman, Bryen, Moolman, & Morris, 2016). Approximately three-quarters of the world's population have access to mobile technology (World Bank, 2012). In fact, in 2014, for the first time, the number of active mobile devices in the world reached 7.22 billion, exceeding the number of people in the world; furthermore, mobile devices are multiplying at a rate 5-times faster than the population growth (Boren, 2014). Mobile technologies have had a profound impact on the lives of many people with disabilities (e.g., Caron & Light, 2015, 2016; Hemsley, Dann, Palmer, Allan, & Balandin, 2015). The broad-based uptake and use of mobile technologies have resulted in greater awareness and acceptance of AAC (McNaughton & Light, 2013). In 2011, Rob Rummel-Hudson, the father of a teenager who uses AAC, summed up the positive impact of mobile technologies as follows:

> … [the iPad] provides a rather elegant solution to the social integration problem. Kids with even the most advanced dedicated speech device are still carrying around something that tells the world "I have a disability". Kids using an iPad have a device that says, "I'm cool". And being cool, being like anyone else, means more to them than it does to any of us. (p. 22)

The availability of mobile technologies and AAC apps has driven down costs and resulted in greater access to AAC: Individuals with complex communication needs and their families are no longer required to wait for professionals to prescribe high-cost AAC technologies; rather, they are empowered to be actively involved in decision-making and purchase (McNaughton & Light, 2013). Mobile technologies offer the potential for greater functionality and interconnectivity. They are not simply speech prostheses; rather they offer the potential to support a wide range of functions. For example, Glenda Watson Hyatt, a web accessibility consultant who uses AAC, described the power of using mobile technologies to meet her communication needs:

> The cool thing was … I had Internet access. When asked what I had been up to, I responded "problogging and ghost writing", and I was able to show what I had written. I also shared the video of me ziplining across Robson Square in downtown Vancouver during the Winter Olympics. The iPad allowed for a deeper level of communication than would have been possible with a single-function AAC device (Hyatt, 2011, p. 25).

Technological advances in AAC are not just limited to increased use of mobile technologies with AAC apps. There have also been substantial advances in the development of alternative access techniques for individuals with severe motor impairments that cannot use standard interfaces (Fager et al., 2019). Especially notable has been the development of eye tracking technologies. This development has opened up more efficient access to communication for individuals with minimal movement (e.g., Ball et al., 2010).

Greater scope and options for communication in society

The very nature of communication in society has changed with the proliferation of technology. People communicate not just through face-to-face interactions and written communication, but also via a wide range of digital

communication platforms (e.g., Facebook[2], Instagram[3], Twitter[4], etc.). These communication platforms have extended the potential reach of communication from a relatively small group of familiar partners seen on a regular basis to millions of potential followers around the world, many of whom interact from different places and at different times (Light & McNaughton, 2014). Access to the Internet and digital communication platforms has offered increased opportunities for communication and engagement by individuals with complex communication needs, free from the time constraints, attitudinal barriers, and accessibility barriers that often limit face-to-face interactions (e.g., Caron & Light, 2015, 2016; Hemsley et al., 2015; Hynan, Murray, & Goldbart, 2014). This access has provided exciting new possibilities for individuals with complex communication needs to participate actively in education, employment, healthcare, and community activities (e.g., Caron & Light, 2015; McNaughton, Light, & Groszyk, 2001; Raghavendra, Newman, Grace, & Wood, 2013). An adult with ALS who relies on AAC described the benefits of these digital communication platforms as follows:

> One of the first abilities I began to lose with ALS was speech. Social events became more uncomfortable the worse my speech became. For me, in many ways my world became more closed in and isolated as my ability to communicate deteriorated. Even with the help of speech assistance [AAC support with speech output], group interaction is difficult. Facebook is a better communication tool for me rather than phone or in person. I'm able to easily interact with groups of friends and family. On Facebook we all are on the same level of communication ability … I am able to reconnect with people socially and my world has expanded even though I'm stuck at home most of the time (Caron & Light, 2015, p. 687).

Use of digital communication platforms and other communication technologies in society has not only expanded the scope of communication, but has also increased the range of options used for expression (Light & McNaughton, 2014). In the past, people without disabilities typically relied on speech and written text for expression; it was primarily individuals with complex communication needs that utilized photos or picture symbols to communicate. With advances in the sharing of digital images, people now utilize a broad range of digital media to augment their communication and support interaction with others across time and space, including photos, videos, and emoji. The widespread use of digital images may level the field in some ways for people with complex communication needs, as these media are now socially accepted and readily available on a wide range of platforms (although it should be noted that literacy skills are required to access most of these platforms).

[2]Facebook is an online social networking and media service. For further information, visit www.facebook.com

[3]Instagram is a social networking service that supports photo and video sharing; it is owned by Facebook. For further information, visit www.instagram.com

[4]Twitter is an online social and news network in which users post short messages or tweets; for further information, see twitter.com

Increased expectations for participation and engagement

Thirty-to-40 years ago, many children with disabilities were excluded from an appropriate education; few adults with complex communication needs had jobs; few were empowered to participate actively in their medical care; and few individuals with complex communication needs of any age had opportunities to participate in their communities in meaningful ways (Mirenda, 2014; Williams, 2000). Now individuals with complex communication needs of all ages and their families have increased expectations for participation in a wide range of environments: educational (e.g., Soto & Zangari, 2009), vocational (e.g., McNaughton, Light & Arnold, 2002; McNaughton et al., 2001), healthcare (Blackstone et al., 2015), and community (Dattilo et al., 2008; Hajjar, McCarthy, Benigno, & Chabot, 2016). These changes in expectations have resulted in a greater breadth of communication needs that must be addressed in AAC service delivery. As a result, service providers must consider new AAC supports, improved skill instruction, and enhanced partner supports to enable individuals who use AAC to meet the breadth of needs (Light & McNaughton, 2014; Light, McNaughton et al., 2019). Each person with complex communication needs requires multiple options for expression, the same opportunity that is afforded those without disabilities. Just having one means of expression for one environment is not adequate. As Williams, Krezman, and McNaughton (2008) emphasized: "One is never enough: Individuals with complex communication needs require more than one device, one communication partner, one communication strategy, one communication environment" (p. 195).

Challenges for the AAC field

Despite the many advances in the AAC field, there remain substantial challenges that must be addressed to ensure that all individuals have access to effective communication and are able to participate to their greatest potential. These challenges include the (a) marginalization of individuals with severe disabilities; (b) need for research-driven technical development; (c) lack of researchers, engineers, and technical developers; and (d) gap between research and everyday practice.

Marginalization of individuals with severe disabilities

The population of individuals with complex communication needs is strikingly diverse; it includes individuals of a wide range of ages, with a wide range of disabilities, who present with a wide range of needs and skills and come from diverse cultural, linguistic, geographic, and socio-economic backgrounds. Although the AAC field has met the needs of some individuals with complex communication needs, there remain many others who do not have access to the AAC supports and services they require. For example, although the proliferation of AAC apps and mobile technologies has opened up new communication opportunities for many individuals with

complex communication needs, these technologies may not be available to those in low-resource communities. Furthermore, they are primarily options for those who have relatively good sensory-perceptual, cognitive, linguistic, and motor skills; and may pose significant challenges for many individuals who have severe disabilities. For example, many young children, older individuals with severe developmental disabilities, and individuals with acquired conditions who face significant linguistic and cognitive limitations (e.g., adults with severe aphasia, dementia) have difficulty learning and using traditional AAC technologies that utilize grid displays with decontextualized AAC symbols (e.g., Brock, Koul, Corwin, & Schlosser, 2017; Light, McNaughton et al., 2019; Trudeau, Sutton, & Morford, 2014). These individuals require more effective language supports to communicate effectively (Fried-Oken, Beukelman, & Hux, 2012; Light & McNaughton, 2012b). Furthermore, many individuals with severe motor impairments resulting in minimal movement need access to technologies and interfaces to meet their complex needs and skills (Fager et al., 2019). For example, a parent of a child with severe cerebral palsy summarized the challenges of eye gaze access to AAC technologies for her son:

> I had hoped it would be a simpler thing for him that he would just select it with his eyes … but because his eyes are attached to his head and his head is attached to the rest of him he never stays still. Even though this is his access method he still has major access issues (O'Neill, 2018, p. 69).

The challenges are exacerbated because individuals who require AAC need to participate in a wide range of environments with varied demands (e.g., education, vocation, healthcare, family, community). Unfortunately, many AAC technologies are not functional across these varied environmental conditions. A parent summed up the challenge as follows:

> He's really dependent on it [AAC technology], and he really needs it with him all the time, but there are still these times or situations where you have to suddenly take away his voice just because of the reality of where technology is at (O'Neill, 2018, p. 64).

Many individuals with complex communication needs require AAC supports over time, across multiple transitions and changing needs and skills (e.g., as children with developmental disabilities grow and develop, as adults with acquired conditions recover, and as those with degenerative conditions experience loss of skills). Frontera et al. (2017) highlighted the importance of framing rehabilitation/habilitation as an ongoing process requiring tune-ups, modifications, or changes at numerous points in time. Sometimes changes happen over an extended time; sometimes individuals with complex communication needs experience significant variation in their needs and skills over the course of a single day because of changes in positioning, fatigue, and medication levels. For example, individuals with severe motor impairments may require multiple adaptations to their alternative-access technologies during the day, each one requiring expert set-up (Fager et al., 2019). Individuals with complex communication needs require AAC supports that are sufficiently flexible to support these changes and transitions seamlessly (Light & McNaughton, 2013).

Furthermore, these technology supports must be as transparent as possible so that a wide range of caregivers can implement and support their use successfully. A parent of a child with disabilities described the demands of AAC intervention as follows:

> It took a lot of effort and concentration and determination. And particularly when you know that there's not a lot of support, it's really up to me … and just to take it on board and take on all that hard work is sort of daunting (Anderson, Balandin, & Stancliffe, 2014, p. 78).

Although many individuals with severe disabilities and their families still face significant challenges meeting their communication needs, research and development for these individuals is lagging behind other technology development. In the past, prior to the surge of mobile technologies and AAC apps, many AAC manufacturers were able to address the needs of individuals with the most severe disabilities by absorbing some of the costs for this specialized research and development into the development of the speech-generating devices used by many. However, now that many individuals with communication disabilities have access to relatively inexpensive mobile technologies and AAC apps to meet their communication needs, the market for specialized AAC devices has shrunk considerably. Assistive technology manufacturers face significant challenges with the development, funding, and support of assistive technologies for those with the most severe disabilities; it is difficult, if not impossible, to re-coup costs. At a time when communication options are increasing for many people, they are extremely limited for those with the most significant disabilities. Increased research and development is required to meet the needs of these individuals, and must address (a) improved access for those with severe motor impairments (e.g., brain–computer interface, multimodal access; Fager et al., 2019), and (b) reduced learning demands for those with significant language and cognitive limitations (Light, McNaughton et al., 2019; Light, Wilkinson et al., 2019).

Need for research-driven technical development

The development of the first AAC technologies more than 30 years ago primarily reflected what was technologically possible at the time combined with the ingenuity and creativity of clinicians and manufacturers. There was minimal, if any, research to elucidate the needs and skills of individuals who required AAC assistive technologies. Specifically, there was a lack of research to provide insight into the basic cognitive, motor, sensory perceptual, and linguistic function of individuals with complex disabilities over time and to determine the implications of these processes for maximizing human–-computer interaction. As noted earlier, there is definitely evidence that traditional AAC technologies have benefitted individuals with complex communication needs across a range of ages and disabilities; however, these traditional AAC technologies may not be optimally designed to meet the needs of all of these individuals. When practice alone (and

not research) drives technology development, the underlying beliefs and/or values may not always be sound (Mirenda, 2017). As a result, AAC technologies may be challenging for some to learn and use (e.g., Brock et al., 2017; Light, McNaughton et al., 2019; Light, Wilkinson et al., 2019; Trudeau et al., 2014). Research is required to examine the cognitive, linguistic, social, sensory perceptual, and motor demands that are imposed on the end-users. For example, Fried-Oken, Mooney, and Bedrick (2018) are currently developing a cognitive demands checklist for AAC technologies with the goal to improve the person-technology match as it relates to cognitive processing demands. Increased research and development are required to ensure that AAC interventions and technologies are truly responsive to the needs of individuals who require AAC and their families. If AAC technologies are research-based, developmentally appropriate, and user-centric, they will result in more effective tools to support the communication and participation of individuals with complex communication needs (Light, McNaughton et al., 2019; Light, Wilkinson et al., 2019).

Lack of researchers, engineers, and technical developers

Worldwide, there is only a relatively small cadre of active researchers, engineers, and technical developers that are conducting high-quality research and development in AAC (McNaughton et al., 2019). As a result, there remain many unanswered questions and many technical problems that have not been solved. The problem is further aggravated by the shortage of doctoral scholars and rehabilitation engineering students developing expertise in AAC. Without a sufficient number of scientists generating sound research to determine effective evidence-based practices and developing effective research-based technology solutions, AAC services will be seriously compromised and individuals with complex communication needs will be at grave risk in all domains: education, employment, health, and community living.

Concerted attention is required to develop the knowledge base in this dynamic field so that technology development, service delivery, policy development, and funding decisions are evidence-based. If we do not act, and act with urgency, to bolster current capacity and build future capacity, the field will not progress and the potential of millions of individuals with complex communication needs will be compromised. Increased numbers of scientifically trained personnel with expertise in AAC research and development are urgently required to meet this need (McNaughton et al., 2019). Building capacity in AAC research and development is especially challenging because of the diversity of needs that must be met across the life span and across disability groups. Researchers and developers in AAC require a broad skill set: They must be knowledgeable in a wide range of research methodologies to address complex problems in the field, and they must work with methodological rigour to ensure robust results (Kent-Walsh & Binger, 2018). Innovative strategies must be explored to recruit high quality graduate students to AAC and to maximize their development and retention in the field. One important venue for building capacity in AAC research and development is the biennial conference of the International Society for Augmentative and Alternative Communication; the AAC Doctoral Student Think Tank[5], hosted by the RERC on AAC, is another.

Gap between research and everyday practice

Furthering research and development will advance knowledge and increase the range of research-based AAC interventions and technology solutions to support the participation of individuals with complex communication needs. This research and development is necessary, but it is by no means sufficient to ensure the communicative competence of individuals who require AAC. The development of communicative competence depends on the uptake and effective implementation of AAC within the daily lives of individuals with complex communication needs, their families, and other communication partners. Over the past 40 years, we have learned a great deal about effective AAC supports and evidence-based practices to enhance communication and improve results for individuals who require AAC (Kent-Walsh & Binger, 2018), but there remains a substantial gap between research and practice. In healthcare generally, it takes an average of 17 years for an evidence-based practice to be incorporated into general practice, and only about half of evidence-based practices ever reach widespread usage (Bauer, Damschroder, Hagedorn, Smith, & Kilbourne, 2015). The challenge is even greater in the AAC field, due to the lack of AAC competencies among service providers. Dana Nieder illustrated this problem in her account of her family's search for effective communication supports for her daughter, Maya:

> From age 1–2.5, we saw at least 13 doctors, seven therapists (four of whom were SLPs), had four outpatient hospital surgeries/procedures, and had a multi-disciplinary meeting to evaluate Maya's service plan … None of these doctors, therapists, or other professionals ever mentioned AAC—and Maya, who had a visible genetic syndrome, severe oral-motor difficulties, and no discernible speech should have been a very clear potential candidate for AAC. This is a huge gap in provider awareness (D. Nieder, personal communication, June 15, 2018).

The number of individuals who require AAC services dwarfs the number of service providers who have expertise in AAC. Many service providers report that they lack expertise in evidence-based AAC practices (e.g., Costigan & Light, 2010; Gormley & Light, in press); this lack of expertise negatively impacts services and outcomes for individuals who require AAC. For example, a speech-language pathologist working with individuals with complex communication needs in a rehabilitation setting summed up the problem when she

[5]In 2017, a 3-day AAC Doctoral Student Think Tank was hosted by the RERC on AAC to build future capacity in AAC research and development. The think tank brought together 22 doctoral students from 14 different universities across the US to network with each other, interact with leaders in the field, and work on developing important and productive lines of research and development (for further information, visit Rehabilitation Engineering Research Center on Augmentative and Communication (2017). *The Doctoral Student AAC Research Think Tank*. Retrieved from https://sites.psu.edu/aacthinktank/).

wrote, "Often times, the limitations are in us; not in our clients or patients" (Gormley & Light, in press).

Pre-service programmes for speech-language pathologists, educators, occupational and physical therapists, and other service providers continue to lag behind in providing research-based pre-service training in AAC (Costigan & Light, 2010; Molt, 2017). There is an urgent need for more effective dissemination and training to build capacity in the field across stakeholders and to support the effective translation of this research to evidence-based practice as well as increased efforts to promote awareness within the general public (McNaughton et al., 2019). Specifically, greater attention should be directed to implementation science in AAC: … "the scientific study of methods to promote the systematic uptake of research findings and other [evidence-based practices] into routine practice" (Bauer et al., 2015).

Future directions to enhance participation for individuals who require AAC

Clearly there is considerable future work that must be undertaken in order to meet the aforementioned challenges and propel the AAC field forward, including, but not limited to, the following: (a) increasing collaboration to meet the needs of those that are underserved, (b) expanding the functionality of AAC technologies, (c) advancing research-driven development of AAC interventions and technology solutions, (d) leveraging innovative technologies to enhance AAC options, and (e) optimizing technology and precision AAC to better meet individual needs.

Increasing research collaboration to meet the needs of individuals who are under-served

As noted earlier, there are many individuals with complex communication needs who do not have access to effective and efficient AAC. Future research is required to develop effective and efficient access technologies for individuals with severe motor impairments, including work to advance brain–computer interfaces, investigate multimodal access techniques, leverage sensing technologies, and explore applications of machine learning to reduce set-up and calibration demands (Fager et al., 2019). Future research is also required to (a) investigate effective and efficient AAC supports that are easily learned and utilized by individuals with significant language and cognitive limitations and the communication partners who support them (Light, McNaughton et al., 2019), and (b) design research-based AAC interface displays that impose minimal demands and support the communication performance of children and adults with developmental or acquired disabilities (Light, Wilkinson, et al., 2019). Concerted efforts are also required to develop low cost solutions that respond to the needs of low resource countries.

Forging new ground and investigating innovative solutions to complex problems always involves risk. Not every project will be a success. However, important learning occurs even within failure, and this learning can serve to propel the field forward. In 2014, Godfrey Nazareth, a biomedical engineer, father, and aviator, who has a neurodegenerative disorder and relies on AAC, urged the field to aim high and rise above the established paradigms of what is believed to be possible for people with significant disabilities: "As da Vinci famously exclaimed, for once you have tasted flight, you will walk the earth with your eyes turned skyward, for there you have been and there you will long to return". Achieving new heights in AAC will require greater collaboration.

Collaboration among stakeholders and disciplines

The challenges faced by individuals that are currently underserved are complex. Understanding these problems and developing innovative solutions requires close collaboration with consumers and their families at every step, from problem definition, to hypothesis testing, to clinical evaluation, to social validation (Frontera et al., 2017). Research and development also requires close collaboration with service providers, researchers, and technical developers with expertise in multiple disciplines, including (but not limited to) engineering, computer science, speech-language pathology, education, psychology, linguistics, cognitive science, motor performance, vision, and occupational/physical therapy. No single discipline has sufficient expertise to solve these complex problems alone. The most innovative research and technical developments often occur at the intersections among multiple disciplines. Maximizing multidisciplinary interactions will require collaboration across multiple sites to bring together the best and the brightest to solve these complex problems. The RERC on AAC is one example of a successful virtual centre that has built collaborations across multiple sites and disciplines to enhance research, development, training, and dissemination in AAC (Rehabilitation Engineering Research Center on Augmentative and Alternative Communication, 2018); the international consortium investigating the aided language skills of children is another example of a successful multi-site research collaboration (von Tetzchner, 2018).

Collaboration with mainstream technology developers

Finding effective solutions also requires more informed and productive interactions with general technology companies and regulatory bodies (Frontera et al., 2017). Historically, the AAC field has been forced to develop retrofit solutions each time new mainstream technologies emerge. This approach is a costly one that delays access to new and emerging technologies for those with complex communication needs. It is critical that AAC stakeholders are at the table with mainstream technology developers to inform the accessibility of technologies for all. In recent years, many mainstream technology manufacturers have taken steps to address the needs of individuals with disabilities. This work is definitely to be applauded; however, the needs of those individuals with the most severe disabilities have still not been effectively addressed. It is essential that technology companies consider the needs not just of those with mild impairments, but also of those with severe disabilities who may need to rely to an

even greater extent on effective and efficient technology use. Rather than attempting to avoid or circumvent the challenges of serving such a heterogeneous population, the field must embrace the challenge of addressing these needs. Developing research-based technologies that are effective and efficient for those with the most severe disabilities can benefit all of society, making mainstream technologies more effective and more efficient for all (Light, Wilkinson et al., 2019). For example, in 2017, Microsoft and Tobii Dynavox launched a mutually beneficial collaboration to make Tobii's eye tracking technology compatible with Microsoft Eye Control, thus bringing eye tracking access to the mainstream; this collaboration has the potential of increasing productivity and improving applications such as gaming, while at the same time making access much easier for individuals with disabilities.

Expanding the functionality of technology supports

Individuals who use AAC need the tools to allow them to be full participants in a wide range of environments: family, school, healthcare, work, and community. In order to fulfil meaningful roles, individuals with complex communication needs require AAC supports that provide seamless, integrated access to the full range of communication that others without disabilities enjoy (McNaughton & Light, 2013). Increasingly, there is the realization that the power of AAC technologies can be tapped to not just augment expressive communication, but also support learning across a breadth of domains (e.g., language learning, literacy instruction, job coaching, community living, meaningful volunteer activities; Light, McNaughton et al., 2019). Communication should not be viewed as the end goal; rather, it is a tool to attain a wide range of educational, vocational, and personal goals. Future research and development is required to extend current work integrating communication supports across applications and environments to support fuller participation of individuals with complex communication needs (Light, McNaughton et al., 2019). In order to support effective participation in society, AAC intervention must extend beyond the individual who uses AAC to address the needs and skills of family and other communication partners (Kent-Walsh, Murza, Malani, & Binger, 2015). Research and development is required to explore the use of AAC technologies as tools to provide just-in-time instruction for communication partners (Light, McNaughton et al., 2019).

Advancing research-driven development of AAC technology solutions

As the development of new AAC supports moves forward, it is essential that this development is user-centric *and* research-based, driven by empirical knowledge of the motor, sensory-perceptual, cognitive, linguistic, and social-relational function of individuals with complex communication needs; and the changes in function over time, for example, as children develop, as adults with acquired conditions recover, or as individuals with degenerative conditions experience decline (Light & McNaughton, 2013). There is mounting evidence demonstrating that, even what seem like relatively minor variables in AAC technology design (e.g., location of the navigation bar, use of color background in displays) can substantially affect the accuracy and efficiency of performance of individuals with developmental or acquired disabilities (see Light, Wilkinson et al., 2019). Although any single one of these variables in isolation may not be sufficiently impactful to impair the performance of individuals without disabilities, the accumulated effects of a number of sub-optimal design features may significantly impact the performance of individuals with disabilities, rendering communication ineffective, inefficient, or completely impossible. Ongoing translational research is needed to build connections from basic research in neuroscience and human function, to AAC research and development and, ultimately, to implementation science in AAC practice. This research should include individuals with complex communication needs and their families each step of the way to ensure that it is consumer and family driven (Frontera et al., 2017).

Frontera et al. (2017) highlighted a number of challenges that complicate rehabilitation research, including the heterogeneity of participants, the intricacies of environmental factors, the necessity of individualized interventions, the need to balance the demands of internal and external validity, and non-specific intervention moderators that are difficult to control. These all apply to AAC intervention research as well, and are further complicated by the diverse range of communication partner variables and the complexities of AAC system variables that must be considered. Frontera et al. cautioned against blind adherence to the belief in the superiority of traditional randomized controlled trials (RCTs), and called for greater diversity in research methodologies to address these challenges. It is not that one methodology is better than another; rather, it is a question of fit between the questions posed and the methods employed. The National Institute on Disability Independent Living and Rehabilitation Research (NIDILRR) of the US has proposed stages of research (i.e., exploration and discovery, intervention development, intervention efficacy, and scaled-up evaluation) as well as stages of development (i.e., proof of concept, proof of product, proof of adoption) to highlight the different goals and methods required to address these challenges (Stages of Development, 2018; Stages of Research, 2018).

Leveraging innovative technologies to serve individuals who require AAC

As research and technology development advance, it is important to look beyond traditional AAC approaches and explore technology innovations that may offer increased options to better meet the needs of individuals who require AAC. For example, several parents of children with cerebral palsy, interviewed in a qualitative study by O'Neill (2018), highlighted their hopes for innovative technology solutions to better meet the needs of their children:

> I would love to see something that would be more discrete. You know, maybe something in an eyeglass, something that she could be using that weren't such a bulky object between her and the world (p. 70).

> I would love for facial recognition technology to be available. I mean if he had a smart home where there were cameras and he could open his mouth. The camera could see that he opened his mouth, so he wouldn't necessarily need a human being there, but he could use his existing, very successful facial gestures … (p. 70).

> We can get augmented reality glasses. Move away from using our hands for all these things (p. 169).

> … It would be really neat if he could use brain waves because there's always going to be a motor component to eye gaze, and he has a very severe motor impairment (p. 151).

As these parents suggest, there is a wide range of innovative technology developments that may offer potential to improve communication for individuals with complex communication needs, including advances in augmented reality, digital image processing, brain–computer interface, sensing technologies and wireless connectivity, and artificial intelligence and machine learning. Some of these are already being explored in the field of AAC; others offer new, as yet unexplored, potential.

Augmented reality

Some individuals with significant language and cognitive limitations have difficulty using abstract symbols, and benefit from more concrete representations to express themselves (e.g., objects). Others may have difficulty shifting attention between an AAC device, the partner, and activities in the real world. And still others may resent the physical barrier that AAC technology creates between themselves and others. Augmented reality (AR) may offer a potential solution to some of these problems. AR is a medium in which digital information is overlaid directly on the real-world experiences of individuals; it can emulate two- or three-dimensional (2D, 3D) objects through holographs and integrate display information (e.g., written words or symbols) as if it is actually present in the individual's environment (Hayden, 2017). AR might be used to support both expression and comprehension. For example, Collins (2017) explored the use of smart glasses to make captions available no matter where the individual is looking. This type of technology might provide a visual AAC translation of partner-spoken input to aided AAC input, potentially supporting comprehension and language learning by individuals with complex communication needs. Richtsmeier and Light (2016) suggested that AR might also provide a means for partners to (a) offer concrete choices between activities that are not immediately present in the environment using 3D holographs to represent options for beginning communicators, or (b) provide a concrete representation of upcoming events as part of a visual schedule to support successful transitions. These are just a few examples of potential applications of augmented reality to enhance the communication of individuals who require AAC and their communication partners. Obviously, future research and development is required to investigate the effects of AR—both positive and negative. For example, does augmented reality support communication or does this manipulation of reality negatively impact the individual's understanding of the world?

Digital image processing

In society generally, people are now making much greater use of a wide array of digital images (e.g., photos, emoji, videos) on various technology platforms to augment their communication with others. These media are now readily available and highly acceptable within society. Technical developments have led to the easy capture, processing, classification, pattern recognition, tagging/labelling, and feature extraction of digital images (e.g., photos, videos). These developments might be leveraged to support the comprehension and expression of individuals with complex communication needs more effectively or efficiently. For example, auto capture of photos or videos of events within a child's life as photo visual scene displays (VSDs) or video VSDs, with auto-tagging of key concepts within these experiences, might provide a quick and easy means to empower the child to have more control in vocabulary selection. Woyke (2017) described a 360-degree selfie, a technology that might allow children with severe motor impairments (who lack independent mobility) the opportunity to virtually explore their world, supporting conceptual development and language learning.

Brain–computer interface

Brain–computer interface (BCI) is one area that is receiving substantial attention in rehabilitation generally and AAC specifically (Chavarriaga, Fried-Oken, Kleih, Lotte, & Scherer, 2017). Important advances in BCI have been made in recent years (see Fager et al., 2019 for a summary of the state of the science). However, there is still substantial need for future research and development to advance more reliable, efficient, and functional BCI for individuals who require AAC and have minimal movement. It is essential to integrate natural language processing into BCI to support message generation because output is very effortful. Much of the work to date has been restricted to laboratory demonstrations with individuals without disabilities; future research and development must involve even greater focus on evaluation with individuals with minimal movement under real life circumstances (Fager et al., 2019). Greg Bieker, a man who has lived with locked-in syndrome for 20 years, described the potential of BCI and the need for future research and development:

> Giving people with locked-in syndrome the option to use a BCI in their daily life can provide so many benefits. It has the potential to give us a sense of control, the ability to communicate independently, and a sense of depth. The challenges of designing a BCI system for people who are social and intelligent are to make it user friendly, reliable, just as easy and fast as other AAC systems, and unobtrusive. That said, BCI also can open new doors, which is hard to do when you're locked-in (Bieker, Noethe, & Fried-Oken, 2011, p. 6).

Sensing technologies and wireless connectivity

Advances in sensing technologies provide another potential opportunity for the AAC field. For example, Fager et al. (2019) describe the development of a novel, wearable sensor system that incorporates an accelerometer, a gyroscope, and a magnetometer to improve access to AAC technologies, for a woman with a brainstem stroke. Given several repetitions of intentional and unintentional movements, the sensor array was able to recognize which movements were intentional and which were not. Sensing technologies might also be used to recognize the subtle, non-conventional, pre-symbolic behaviours of individuals with severe multiple disabilities and suggest consistent linguistic maps for partners (e.g., recognizing that a child reaching towards an object or person and wiggling his or her fingers means "I want it"). Whereas parents and other familiar communication partners may have learned to recognize and interpret these non-conventional signals accurately, other communication partners may not do so consistently. In addition, emerging wearable sensing technologies that measure a range of physical and physiological parameters might provide another source of data to help partners to better determine the communicative intent of individuals who are essentially locked in.

Artificial intelligence and machine learning

The AAC field may benefit from harnessing smart technologies that utilize artificial intelligence (AI) and machine learning. Machine learning has already been applied in AAC, for example, in the work on natural language processing (e.g., Higginbotham, Lesher, Moulton, & Roark, 2012). AAC technologies will never replace expert service providers or skilled communication partners. However, as machine learning/AI improves, AAC technologies may be designed to assist in identifying an individual's intrinsic needs and skills, as well as extrinsic variables in the environment, and they may be able to suggest appropriate, individual adaptations in real time (Fager et al., 2019). For example, context-aware technologies might assess ambient noise and suggest adjustments to speech output volume or determine location and propose relevant vocabulary.

In other cases, AI/machine learning may be harnessed to provide smart supports for parents, professionals, and other communication partners. Applying machine learning approaches, AAC technologies might identify key transition points in language development and suggest next steps for parents and service providers of children with complex communication needs (e.g., suggesting the introduction of a greater range of language concepts for children with an over-abundance of nouns or suggesting the transition from graphic symbols to written text; Light, McNaughton et al., 2019). These types of smart supports may assist parents and professionals (especially those with limited experience and training in AAC) in the complex decision-making that is required to support the development of communicative competence by individuals that require AAC. The development of effective AI supports is not without significant challenges; the greatest of these is the need for sufficient high-quality data to bolster machine learning. Garnering such data will require a coordinated effort across multiple centres and scientific fields.

Optimizing technology and precision AAC

Given the unique constellations of needs and skills presented by each individual who uses AAC, a "one-size-fits-all" approach has seldom been successful. In the field of medicine, there is increasing recognition of the importance of *precision* medicine, that is, decisions, interventions, technologies, and practices that are customized to the individual (Ashley, 2015). In many ways, the field of AAC has been in the forefront of precision intervention for many years (Beukelman, 2016). However, current approaches to personalization of AAC technologies and intervention require substantial time, effort, and expertise on the part of AAC service providers, families, and other communication partners.

One of the challenges of precision AAC is the intricacy of the decision-making process, which requires consideration of a wide array of factors related to the individual who requires AAC, the communication partners, the environment, and the AAC system. Decision-making is further complicated by the fact that these factors may change significantly over time, within a single day, or across weeks, months, or years. Weighing all of these factors to design effective AAC intervention is a complex process, especially for novices that have limited experience and training (McNaughton et al., 2019). As machine learning and artificial intelligence improve, there will be greater potential for AAC technologies to support parents, professionals, and other communication partners at key decision-making points in intervention by analyzing available data and proposing next steps. There will be greater potential for AAC technologies to identify an individual's intrinsic needs and skills, as well as extrinsic variables in the environment, and then provide appropriate, individually adapted communication supports in real time. Wobbrock, Gajos, Kane, and Vanderheiden (2018) called for an *ability-based design* in the development of new technology: the creation of technologies that can rapidly and transparently adapt to the individual's abilities, rather than technologies to which an individual must adapt.

Conclusion

Forty years ago, few individuals with complex communication needs had access to AAC to enhance their communication, and those who did only received AAC as a last resort. Only a few individuals with complex communication needs had the opportunity and the supports required to participate successfully in education, employment, healthcare, or community living. Over the years, through the hard work and advocacy of individuals with complex communication needs, their families, caregivers, service providers, researchers, AAC manufacturers, app developers, policy-makers, and government agencies, there is now an increased array of AAC supports and services available for individuals with complex communication needs, as well as increased research and

development to establish the evidence-base. These efforts have proved that it is possible for individuals who require AAC to attain meaningful outcomes in education, employment, healthcare, and community living.

Yet, despite these advances, the work is far from done. Concerted research and development is required to address the needs of those with the most complex disabilities to provide access to communication and reduce their marginalization and isolation in society. This work will require concerted advocacy to ensure that individuals with complex communication needs have meaningful opportunities within society. Schuyler Hudson, a young woman who uses AAC, and her father, Rob Rummel-Hudson, delineated the challenge:

> My point, … for every educator and every employer and policy maker and citizen, is that the only way the world will work for people with disabilities like Schuyler is if it becomes a place defined by opportunity. Inclusion can't be a policy or a goal; the time for that is long behind us now. Meaningful inclusion has to reside in our DNA as a society. The idea that we should identify disabled children's limitations and predict future outcomes based on what we see or think we see was never a good model. It's an unforgivable one now … We need only create a just and inclusive society with opportunities and authentic relationships and real equity. And then get the hell out of their way (Rummel-Hudson & Hudson, 2018).

Future research is required to reduce disparities and close the gap between what has been established through research as possible and what actually occurs in the daily lives of many individuals with complex communication needs. This work is urgent. Further time must not be lost in the lives of children and adults who require AAC. As Bob Williams said so eloquently:

> The silence of speechlessness is never golden. We all need to communicate and connect with each other—not just in one way, but in as many ways as possible. It is a basic human need, a basic human right. And more than this, it is a basic human power (Williams, 2000, p. 248).

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