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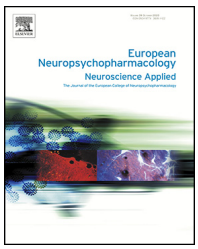

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The role of digital medicine in autism spectrum disorder

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Treatment outcome

Abstract
The field of digital medicine is concerned with the use of technologies as tools for measurement and intervention in the service of human health (Coravos et al, 2019), and may facilitate development of improved therapies for ASD. The use of established and emerging technologies to diagnose, assess, treat, and coordinate care expanded widely over the past ten years. Technologic advances promise to foster earlier and more accurate diagnosis, improved disposition, treatment access and planning, and provide better outcomes and quality of life for individuals with ASD. Two main areas are reviewed below: 1) assessment diagnosis, and outcome, and; 2) digital therapeutics.

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1. Assessment, diagnosis, and outcome

A variety of novel biotechnologies are used in ASD treatment development research, ranging from metabolomics, genomics and proteomics, microbiome, or neuroimaging, to test theories such as neuroinflammation or immunologic processes, excitation/inhibition imbalance, neuropeptides, endocannabinoids and others (Pandina et al., 2020). These approaches are now being complemented with sensor-based approached. Wearables and other peripheral biosensors such as electroencephalography (EEG), eye-tracking, facial affect recognition, electrocardiogram and actigraphy may serve as novel measures of behavior or physiology. Biosensors are being studied to identify biomarkers, either individually or in a coordinated system (Ness et al., 2019). Though

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experimental, biosensors hold promise for use in stratification and outcome measurement (Loth et al., 2017).

Biosensors may have clinical applications as well, and when combined with machine learning approaches may be utilized to identify and measure behaviors, symptoms, or biological factors related to ASD. For example, eye-tracking (as a measure of social attention), motor behavior (to measure repetitive behaviors), or facial affect (social and emotional responsivity) may facilitate and enhance screening or early diagnosis, or assess outcome, particularly when combined with machine learning approaches (Sapiro et al., 2019). Integrated systems using biosensors and web and mobile phenotyping tools are used for research (Ness et al., 2019), but could have clinical utility for tracking treatment outcome (Bangerter et al., 2019).

Exploration of large healthcare databases using ML or artificial intelligence approaches has enhanced our knowledge of ASD (Sapiro et al., 2019), but has had limited impact on clinical practice. Machine learning (ML) is commonly used to improve autism surveillance, but also for feature identification of ASD-specific characteristics for EEG or neuroimaging, tracking health outcomes over time, and creating algorithms for blood-based biomarkers (Hyde et al., 2019). Big data is an important area of research and is proposed as one method of understanding ASD heterogeneity, but with only limited application thus far (Lombardo et al., 2019).

2. Digital therapeutics

Many mobile and web-based treatment tools have been developed, including use of robots, virtual reality-based programs, gaming platforms, to either directly increase engagement and enhance skills such as communication of social interaction, or indirectly to facilitate therapy outcomes by providers or caregivers. Direct digital therapies are more sporadically used, mainly in pilot research, with limited evidence: expanded evidence may lead to more mainstream use in future. Facilitative tools are used more widely in clinical care. A recent review suggests that robots and games may be used as assistive technologies, particularly for social skill training and acquisition (DiPietro et al., 2019). Careful assessment of risks and benefits of digital therapies in controlled trials can inform potential negative impacts such as dependence, increased social isolation, and further delay in spoken language development. Electronic healthcare records have programmed care plans to improve care delivery, resulting mainly in improved screening rather than better outcomes (Downs et al., 2019). Digital platforms that train language skills, social perception (facial affect) and decision-making are emerging, with growing evidence. Perhaps the most promising impact of technology on treatment outcome is the systematic increase in available care via telemedicine, facilitating direct services. Used mainly for screening, diagnosis, and medical/psychiatric follow-up, pilot telemedicine programs for parent or clinician behavioral support tools have shown some evidence of effectiveness (Ferguson et al., 2019), and should be expanded due to limited regional diagnostic and treatment services. Telemedicine represents a major opportunity to improve behavioral, psychiatric, and other medical care for individuals with ASD, given the dearth of specialized treatment providers. Combining assistive technologies that may increase behavioral rehearsal and generalizability, allow skill assessment, in combination with multimodal in-person and remote (i.e., telemedicine) care may give greater access and help with development of better standards for care.

3. Conclusion

Use of digital medicine and technology to improve diagnosis and care has not yet delivered on its early promise: tools are not well constructed, are uncoordinated and siloed, limited to small pilot studies in research setting, and 85–90% of individuals with ASD have defied attempts to subtype by behavioral, symptomatic, or biologic methods. More systematic research, focused on robust demonstration of the utility of digital approaches to aid diagnosis and real-world treatments, parsing ASD heterogeneity, and improving access to care, is needed.

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Conflict of interest

None.

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