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Effects of early swimming in infants with autism spectrum disorders

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ABSTRACT

The number of individuals with autism spectrum disorder (ASD) affecting the development of their perceptual-motor skills and social functioning has been rapidly increasing in recent decades. It is essential to find a novel and effective way for them to develop their skills. Computer systems could improve diagnostic assessment, provide significant support for research, and enhance communication, as well as the assessment of the impact of early swimming on health, motor, social, and cognitive development. Research on early swimming exposure using animal models can provide insights into potential effects on various developmental aspects. Laboratories create genetically modified mice or fish carrying gene variations associated with ASD. To study the behavior of mice or fish, researchers often use video recording, including infrared cameras that enable activity recording without disrupting animal behavior. Video recordings are analyzed using software that can identify and track specific behavioral patterns, movement, or other parameters of interest. This allows researchers to quantify and analyze data in a way that would be challenging or impossible with other methods. The aim of this study was to analyze existing research results that examined early swimming in newborns and infants with ASD, as well as animal models (mice, fish, etc.), to illustrate how water exposure affects their health and development. Additionally, the study aimed to enhance early swimming programs for individuals with ASD through computerized systems.

Keywords: early swimming, autism spectrum disorders, technology

INTRODUCTION

Water activities for young children attracted the attention of researchers as early as the second half of the 20th century (Fouace, 1970). It has been discovered that early swimming, or “baby swimming,” can positively impact the development of individuals with autism spectrum disorder (ASD). ASD is a complex neurodevelopmental disorder characterized by atypical social behavior, repetitive sensory-motor behavior, and difficulties in verbal and non-verbal communication (Hirota & King, 2023). Symptoms can be observed before the age of three, and diagnosis is possible around 18 months of age (Brentani et al., 2013). In addition to these characteristics, other emotional states such as depression, anxiety, and fear have been noted (Asdaq et al., 2024; Güeita-Rodríguez, 2021; Stevanović, 2021). The causes are considered to include genetic events, metabolic disorders, infectious diseases, and structural abnormalities in the brain (Roy et al., 2015). In addition to being a popular physical activity, it has been found that individuals with ASD greatly enjoy the water environment and the increased freedom of movement (Lee & Poretta, 2013; Pan, 2010; Yilmaz et al., 2004). The buoyant force, turbulence, and resistance create unique conditions for easier learning and the development of motor skills (Lee & Poretta, 2013). Various water-based programs, from simply being in the water to targeted training, have shown positive effects on gross and fine motor skills, visual perception of movement, and cognitive flexibility in children with and without ASD (Alaniz et al., 2017; Brito Mancheno, 2024; Caputo et al., 2018; Ennis, 2011; Fragala-Pinkham et al., 2010; Hariri et al., 2022; Pan, 2010, 2011; Santos et al., 2023; Yilmaz et al., 2010). Aquatic programs for children with ASD have shown improvements in swimming skills, physical fitness, social interaction and behavior, water safety, and a reduction in stereotypical self-stimulatory behavior (Fragala-Pinkham et al., 2011; Güeita-Rodríguez, 2021; Lawson et al., 2020; Prupas et al., 2006; Yilmaz et al., 2004). In addition to positive changes in motor skills, positive changes in the behavior of children with ASD have been observed (Johnson et al., 2021) as well as in communication skills (Azimigarosi et al., 2020). The impact of swimming for babies, aged 3-36 months, is significant because there is no break in water exercise between baby swimmers and the age when swimming techniques are taught (Kocić et al., 2023). Swimming from an early age contributes to physical health, improved cognitive functioning in children, provides multisensory stimulation to the somatosensory system (Piljak & Kocić, 2022), and offers benefits for premature and newborn babies (Santos et al., 2023). Early swimming intervention is a non-invasive method that has been proven to enhance brain development in young children and treat neurodevelopmental disorders (Meng et al., 2022). The

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Table 1. Inclusion and exclusion criteria for papers

Inclusion criteria	Exclusion criteria
Swimming for babies and water exposure for newborns and infants with ASD	Abstracts without displayed full papers
Studies involving components influenced by swimming	Sample of participants not falling within newborns and infants up to 36 months or an animal model not corresponding to the age
Participants under 3 years of age with a primary diagnosis of ASD	Research including children over 36 months of aga as study participants who are not from the ASD
Newborns and infants of both genders up to 36 months of age	Research including children disabilities, premature infants, or sick children as study participants who are not from the ASD
Water activities and swimming programs for babies and for the animal model of ASD	
Studies involving computer system to enhance diagnostic assessment and provide significant support for research and the assessment of the impact of early swimming	
Research encompassed until October 2023	

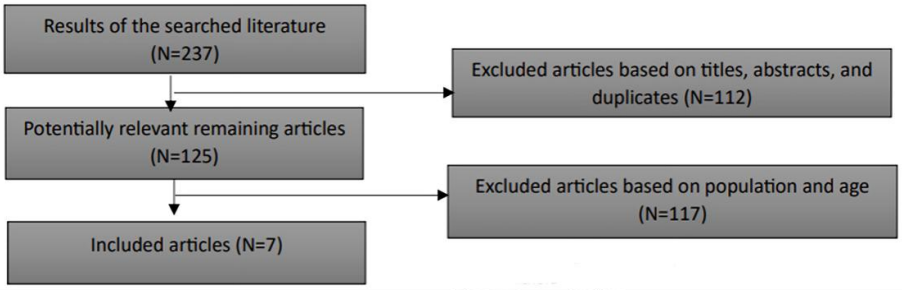


Figure 1. The process of searching and selecting articles (Source: Author's own elaboration)

development of technology has spurred new research, monitoring, and early swimming training (Guo, 2021) and in recent decades has provided much useful information in studies related to ASD (Vyas, 2021). The ability to mimic biological design enables computers to perform various tasks (Kumar et al., 2021), including measuring the position of children with ASD while they swim (Pan et al., 2023). The aim of this study was to analyze existing research results that examined swimming in newborns and infants with ASD, illustrating how early swimming and water exposure affect their health, motor, social, and cognitive development through computer-assisted technology.

METHOD

The inclusion criteria were studies conducted on infants with ASD and animal models, assessing the impact of swimming on their health, motor, social, and cognitive development, as well as water behavior patterns (water familiarization, overcoming fear of water, floating, swimming with song and rhythm, learning breathing techniques, and spatial awareness). **Table 1** displays the corresponding criteria based on which specific studies were included in this review and excluded from it.

Search Strategy

A systematic literature search was carried out using the following electronic databases: Web of Science, PubMed, Google Scholar, KoBSON, and SCIndeks. The final search was completed in October 2023. The search strategy employed systematic terms such as ASD, autism, baby swimming, development, motor development, water exposure, early swimming, sport, health, infant swimming, swimming benefits, motor ability, and others. Titles and abstracts of all articles that satisfied the inclusion criteria were evaluated, with full-text articles then selected for detailed analysis.

The search identified 237 potentially relevant articles related to swimming and water exposure (including activities such as water familiarization, overcoming fear of water, floating, swimming with song and rhythm, learning breathing techniques, and developing spatial awareness) for newborns, infants, and infants with ASD. After screening titles, abstracts, and removing duplicates, 112 studies were excluded. Of the remaining 125 articles, 117 were excluded based on criteria such as age, premature birth, participants not on the autism spectrum, or individuals with other types of disabilities. This screening process resulted in 8 studies that were selected and analyzed in this review. A detailed overview of the literature search and selection process is presented in **Figure 1**.

RESULTS

The results of the studies included in this research are presented in **Table 2**. Among all the studies, three were conducted on rats aged 8 days, equivalent to children aged 1 to 2 years. Three studies were conducted on the animal model of autism in zebrafish. One of the included studies was conducted on children diagnosed with ASD. The treatments administered to the

Table 2. Characteristics of the included studies

Author(s)	Participants	Activity	Instruments	Results
An et al. (2023)	Rats	Swimming with resistance	Computer monitoring	Poor muscle strength in mice with modified Shank3 gene, improvement in strength after intervention, and exercise positively influences the treatment of neuro-pathology in ASD with gut microbiota
Dan et al. (2023)	Rats	Swimming	Computer monitoring	Swimming enhances social behavior, learning, and memory capacity
Kozol et al. (2015)	Zebrafish	Water immersion and swimming	Camera & software	Reducing Singap1 or Shank3 genes or both genes results in slower development, unproductive movement, and cell death
Liu et al. (2018)	Zebrafish	Swimming	Computer monitoring, video track software, & camera	Mutation arising as a result of CRISPR/Cas9 gene editing, established morphological, behavioral, and neurological characteristics in early and adult age
Liu et al. (2021)	Zebrafish	Water immersion and swimming	Video cameras & computer monitoring	The lack of the Shrank3 gene causes social deficits and stereotypical behaviors and water physical activity has positive effects on stereotypical behaviors
Meng et al. (2022)	Rats	Swimming	Infrared cameras & computer monitoring	Improvement of social interaction, social memory, and reduction of stereotypical behaviors
Rogers et al. (2010)	Boys with ASD	Water immersion and swimming	Multicolored hair bands	Increase in motivation, development of positive emotions, rise in desire for activities, and positive changes in speech

participants in these studies included activities ranging from water immersion to resistance swimming. The results indicate a connection between early swimming and motor, social, and cognitive development. It has been found that swimming has a positive effect on neurodegenerative diseases that can occur due to the deficiency or mutation of the Shank3 gene. In addition to increasing muscle strength and endurance, improving social interaction, social memory, and reducing repetitive behaviors, swimming plays a significant role in the prevention and recovery of neurodevelopmental disorders.

DISCUSSION

ASD is a neurodevelopmental disorder characterized by deficits in verbal and nonverbal communication, social impairments, and stereotypical behaviors (Kozol et al., 2015). In addition to these characteristics, ASD may involve motor impairments, reduced intellectual abilities, sensory disorders, obsessive-compulsive disorders, and attention deficits (Hewitson, 2013). It manifests before the age of three during the early stages of brain development. The prevalence of this phenomenon has been increasing annually. Intentional deletion or mutation of the Shank3 gene in laboratory conditions leads to developmental disorders characteristic of ASD (An et al., 2023). The deficiency of this gene is considered the most common risk factor for the onset of ASD. Swimming represents both a fun physical activity and an essential life skill that every child should master at an early age (Anušić, 2020). Early water activities have a positive effect on children's motor development (Piljak & Kocić, 2022) and ensure better adaptation to new situations (Diem, 1982). Water activities require adaptability and are considered the most effective exercise program for neurodevelopment, especially in infants and children (Cheng et al., 2018). Programs for babies involving water exposure and/or swimming improve early motor development in infants (Borioni et al., 2022; Dias et al., 2013; Leo et al., 2022; Pereira et al., 2011; Piljak & Kocić, 2022; Sigmundsson & Hopkins, 2009), have a positive impact on neuro-psychomotor development (Araujo et al., 2023; García et al., 2016), and enhance visual perception of movement (Blystad & van der Meer, 2022). Therefore, water activities from an early age stimulate and enhance the development of infants across various aspects. Swimming plays a significant role in maintaining mental and physical health, as it is crucial for the nervous system, skeletal muscles, and cardiorespiratory function (Aguiar et al., 2011). Additionally, it helps alleviate symptoms in ASD (Ennis, 2011; Pan, 2010; Yanardag et al., 2013; Yilmaz et al., 2004) and has a positive effect on treating ASD (An et al., 2023). Mechanisms through which swimming improves neurological disorders include the expression of neurotrophic factors (Boracı et al., 2020; Dan et al., 2023; Meng et al., 2022; Sigwalt et al., 2011), changes in synaptic structural proteins (Dan et al., 2023; Liu et al., 2018; Meng et al., 2022), alterations in synaptic receptor expression (Boracı et al., 2020; Dan et al., 2023; Ko et al., 2013; Meng et al., 2022), and modifications in neurotransmitter release (Dan et al., 2023; Leite et al., 2012; Meng et al., 2022). Many studies conducted on animal models (Fontana et al., 2022; Kalueff et al., 2013; Meshalkina et al., 2018; Ogi et al., 2021; Oliveira, 2013) show that the loss or mutation within the Shank3 gene can induce stereotypical behavior and social impairments, which are considered characteristic of ASD (Dan et al., 2023; Liu et al., 2021; Mei et al., 2016; Meng et al., 2022; Peca et al., 2011; Zhu et al., 2018). This deficiency in the Shank3 gene results in structural changes in brain proteins (Dan et al., 2023; Meng et al., 2022; Peca et al., 2011; Wang et al., 2017; Yoo et al., 2018) responsible for social behavior, communication, and cognition (Liu et al., 2021). The age of the animal models corresponds to the age of 1-2 years in humans, which is the earliest period for ASD diagnosis (Dan et al., 2023; Meng et al., 2022). In animal models lacking the Shank3 gene and exposed to swimming treatment, positive changes within brain synapses have been observed. This suggests that swimming, as a multisensory and motor stimulation, can greatly improve the development of synaptic abnormalities characteristic of ASD. The early postnatal period is crucial for the prevention and treatment of diseases caused by Shank3 gene mutations (Dan et al., 2023; Liu et al., 2021; Meng et al., 2022). Studies conducted on individuals with ASD focus on motor and social skills. The results of these studies indicate improvements in physical fitness and endurance in children with autism (Fragala-Pinkham et al., 2008; Pan, 2011; Yanardag et al., 2013), as well as the development of social interaction, emotions, and learning (Chu & Pan, 2012; Ennis, 2011; Pan, 2011). In contrast to the development of these skills, a reduction in stereotypical behavior has been observed in children with ASD (Yilmaz et al., 2004).

CONCLUSION

ASD is a neurodevelopmental disorder characterized by social impairment and stereotyped behavior, and its incidence rate is increasing year by year. Analyzed studies confirm the potential of early swimming therapy for ASD. Early swimming programs for infants, including activities for infants aged 3-36 months, have a positive impact on the development of motor, social, and cognitive abilities. Water provides unique sensory stimulations that can assist children with autism in processing and integrating sensory information, contributing to improving their ability to cope with their environment. Movement in water stimulates the function of different muscle groups, strengthens muscles, and improves coordination of movement, while group swimming provides an opportunity for the development of social skills, contributing to improved communication and social integration. Analyzing early swimming intervention studies on animal models (mice and zebrafish) of ASD has yielded similar results in behavior to previous authors. These models can provide important insights into the functioning of genes responsible for the onset of ASD and potential implications for people with ASD. The Shank family (SHANK1, SHANK2, and SHANK3) has become a powerful gene for modeling ASD in animals. This research approach on animal models indicates the connection between genetics, gut microbes, behavior, and the impact of exercise (in this case, swimming) on processes related to ASD. It is essential to note that, although this research can provide useful information about the potential effects of early exposure to swimming, the direct transfer of results to humans must be approached with caution. Nevertheless, this research can contribute to understanding the complex connections between genes, physiology, and behavior in the context of neurological disorders such as ASD. It can also provide a foundation for further study and a better understanding of the potential benefits or challenges of early exposure to swimming in different biological contexts. Early swimming intervention reduces stereotyped behavior and improves social deficits, making it one of the most effective exercise programs for neurodevelopment and neuroplasticity. Challenges in assessing children with ASD in the early ages of 3 to 36 months and the lack of available literature on early “baby swimming” pose certain limitations in research. The scarcity of available literature on the impact of swimming for babies and difficulties in collecting enough infant participants are likely causes for sometimes arbitrary age selection in the literature, leading to a series of inconsistent results. There is limited information on this topic, but the results show that early swimming for babies is extremely beneficial for overall development. Studies examining the use of computers, technology, and visual aids to supplement and improve swimming instruction for participants with ASD are valuable in diagnosing ASD, therapy, and research in general. It is worth noting that further research, both on animal models and participants, will be needed to understand the specific mechanism by which swimming improves ASD.

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REFERENCES

Aguiar, J. A. S., Castro, A. A., & Moreira, E. L. (2011). Short bouts of mild-intensity physical exercise improve spatial learning and memory in aging rats: Involvement of hippocampal plasticity via AKT, CREB and BDNF signaling. *Mechanisms of Ageing and Development, 132*(11-12), 560-567. https://doi.org/10.1016/j.mad.2011.09.005

Alaniz, M. L., Rosenberg, S. S., Beard, N. R., & Rosario, E. R. (2017). The effectiveness of aquatic group therapy for improving water safety and social interactions in children with autism spectrum disorder: A pilot program. *Journal of Autism and Developmental Disorders, 47*, 4006-4017. https://doi.org/10.1007/s10803-017-3264-4

An, S., Zhen, Z., Wang, S., Sang, M., & Zhang, S. (2023). Intestinal microbiota is a key target for load swimming to improve anxiety behavior and muscle strength in Shank3$^{-/-}$ rats. *Research Square*. https://doi.org/10.21203/rs.3.rs-2926253/v1

Anušić, V. (2020). Baby swim alphabet: What should parents know about baby swimming? *Swimming Dad*. https://www.swimmingdad.com/single-post/baby-swim-alphabet-what-should-parents-know-about-baby-swimming

Araujo, L. B., Mélo, T. R., & Israel, V. L. (2023). Improvements in babies’ neuropsychomotor development after family-centered kids intervention therapy–Aquatic environment (KITE): Biopsychosocial approach. *Early Child Development and Care, 193*, 33-45. https://doi.org/10.1080/03004430.2022.2048828

Asdaq, S. M. B., Alshehri, S., Alajlan, S. A., Almutiri, A. A., & Alanazi, A. K. R. (2024). Depression in persons with disabilities: A scoping review. *Frontiers in Public Health, 12*. https://doi.org/10.3389/fpubh.2024.1383078

Azimigarosi, S., Arjmandnia, A., Mohseni Ezhei, A., & Asgari, M. (2020). Effectiveness of hydrotherapy on communication skills of children with autism spectrum disorder: A single case study. *Quarterly Journal of Child Mental Health, 6*(4), 31-40. https://doi.org/10.29252/jcmh.6.4.5

Blystad, J. B., & van der Meer, A. L. H. (2022). Longitudinal study of infants receiving extra motor stimulation, full-term control infants, and infants born preterm: High-density EEG analyses of cortical activity in response to visual motion. *Developmental Psychobiology, 64*, Article e22276. https://doi.org/10.1002/dev.22276

Boracı, H., Kirazlı, Ö., Gülhan, R., Yıldız Sercan, D., & Şehirli, Ü. S. (2020). Neuroprotective effect of regular swimming exercise on calretinin-positive striatal neurons of Parkinsonian rats. *Anatomy and Science International, 95*(4), 429-439. https://doi.org/10.1007/s12565-020-00538-y

Borioni, F., Biino, V., Tinagli, V., & Pesce, C. (2022). Effects of baby swimming on motor and cognitive development: A pilot trial. *Perceptual and Motor Skills, 129*, 977-1000. https://doi.org/10.1177/00315125221090203

Brentani, H., Paula, C. S., Bordini, D., Rolim, D., Sato, F., Portolese, J., Pacifico, M. C., & McCracken, J. T. (2013). Autism spectrum disorders: An overview on diagnosis and treatment. *Revista Brasileira de Psiquiatria, 35*(1), 62-72. https://doi.org/10.1590/1516-4446-2013-S104

Brito Mancheno, F. D. (2024). Natación en niños: Beneficios científicos para un desarrollo acuático temprano [Swimming in children: Benefits for early aquatic development]. *MENTOR Revista de investigación Educativa y Deportiva, 3*(8), 700-718. https://doi.org/10.56200/mried.v3i8.7640

Caputo, G., Ippolito, G., Mazzotta, M., Sentenza, L., Rosaria, M., Muzio Salzano, S., & Conson, M. (2018). Effectiveness of a multisystem aquatic therapy for children with autism spectrum. *Journal of Autism and Developmental Disorders, 48*(6), 1945-1956. https://doi.org/10.1007/s10803-017-3456-y

Cheng, M., Cong, J., Wu, Y., Xie, J., Wang, S., Zhao, Y., & Zang, X. (2018). Chronic swimming exercise ameliorates low-soybean-oil diet-induced spatial memory impairment by enhancing BDNF-mediated synaptic potentiation in developing spontaneously hypertensive rats. *Neurochemical Research, 43*(5), 1047-1057. https://doi.org/10.1007/s11064-018-2515-x

Chu, C.-H., & Pan, C.-Y. (2012). The effect of peer- and sibling-assisted aquatic program on interaction behaviors and aquatic skills of children with autism spectrum disorders and their peers/siblings. *Research in Autism Spectrum Disorders, 6*(3), 1211-1223. https://doi.org/10.1016/j.rasd.2012.02.003

Dan, X., Yunchen, M., Shasha, A., Wenshu, M., Hanran, L., Weinan, Z., Yaqi, X., Xinyu L., Xiaoxi, W., Mingjuan, L., Xiaoyan, Z., Zhang, Z., Yu, Z., Haodong, Y., Chen, Z., Rong, Z., & Zhiping, Z. (2023). Swimming exercise is a promising early intervention for autism-like behavior in Shank3 deletion rats. *CNS Neuroscience & Therapeutics, 29*, 78-90. https://doi.org/10.1111/cns.13920

Dias, J. A., Manoel, E. J., Dias, R. B., & Okazaki, V. H. (2013). Pilot study on infant swimming classes and early motor development. *Perceptual and Motor Skills, 117*, 950-955. https://doi.org/10.2466/10.25.PMS.117x30z2

Diem, L. (1982). Early motor stimulation and personal development. *Journal of Physical Education, Recreation & Dance, 53*, 23-25. https://doi.org/10.1080/07303084.1982.10629456

Ennis, E. C. (2011). The effects of physical therapy directed aquatic program on children with autism spectrum disorders. *The Journal of Aquatic Physical Therapy, 19*(1), 4-10.

Fontana, B. D., Müller, T. E., Cleal, M., De Abreu, M. S., Norton, W. H., Demin, K. A., Amstislavskaya, T. G., Petersen, E. V., Kalueff, A. V., Parker, M. O., & Rosemberg, D. B. (2022). Using zebrafish (danio rerio) models to understand the critical role of social interactions in mental health and wellbeing. *Progress in Neurobiology, 208*, Article 101993. https://doi.org/10.1016/j.pneurobio.2021.101993

Fouace, J. (1970). *Pourquoi nager avant de marcher et après* [Why swim before walking and after]. France Maman.

Fragala-Pinkham, M. A., Haley, S. M., & O'Neil, M. E. (2008). Group aquatic aerobic exercise for children with disabilities. *Developmental Medicine & Child Neurology, 50*(11), 822-827. https://doi.org/10.1111/j.1469-8749.2008.03086.x

Fragala-Pinkham, M. A., Haley, S. M., & O'Neil, M. E. (2011). Group swimming and aquatic exercise programme for children with autism spectrum disorder: A pilot study. *Developmental Neurorehabilitation, 14*(4), 230-241. https://doi.org/10.3109/17518423.2011.575438

Fragala-Pinkham, M. A., O'Neil, M. E., & Haley, S. M. (2010). Summative evaluation of a pilot aquatic exercise program for children with disabilities. *Disability and Health Journal, 3*, 162-170. https://doi.org/10.1016/j.dhjo.2009.11.001

García, J. L., Sánchez-López, A. M., Baena García, L., Noack Segovia, J. P., & Aguilar Cordero, M. J. (2016). Influencia de la actividad física acuática sobre el neurodesarrollo de los bebés: Revisión sistemática [Influence of aquatic physical activity on the neurodevelopment of infants: Systematic review]. *Nutrición Hospitalaria, 33*(5), 10-17. https://doi.org/10.20960/nh.515

Güeita-Rodríguez, J. (2021). Effects of aquatic therapy for children with autism spectrum disorder on social competence and quality of life: A mixed methods study. *International Journal of Environmental Research and Public Health, 18*(6), Article 3126. https://doi.org/10.3390/ijerph18063126

Guo, H. (2021). Computer aided system for swimming teaching and training. In M. A. Jan, & F. Kahn (Eds.), *Application of big data, blockchain, and internet of things for education informatization. BigIoT-EDU 2021. Lecture notes of the institute for computer sciences, social informatics and telecommunications engineering, vol 391* (pp. 43-52). Springer. https://doi.org/10.1007/978-3-030-87900-6_6

Hariri, R., Nakhostin-Ansari, A., Mohammadi, F., Memari, A. H., Oskouie, I. M., & Haghparast, A. (2022). An overview of the available intervention strategies for postural balance control in individuals with autism spectrum disorder. *Autism Research and Treatment, 2022*, 3639352. https://doi.org/10.1155/2022/3639352

Hewitson, L. (2013). Scientific challenges in developing biological markers for autism. *OA Autism, 1*(1), Article 7. https://doi.org/10.13172/2052-7810-1-1-474

Hirota, T., & King, B. H. (2023). Autism spectrum disorder. A review. *JAMA, 329*(2), 157-168. https://doi.org/10.1001/jama.2022.23661

Johnson, N. L., Bekhet, A. K., Karenke, T., & Garnier-Villarreal, M. (2021). Swim program pilot for children with autism: Impact on behaviors and health behaviors and health. *Western Journal of Nursing Research, 43*(4), 356-363. https://doi.org/10.1177/0193945920948867

Kalueff , A. V., Gebhardt, M., Stewart, A. M., Cachat, J. M., Brimmer, M., Chawla, J. S., Craddock, C., Kyzar, E. J., Roth, A., Landsman, S., Gaikwad, S., Robinson, K., Baatrup, E., Tierney, K., Shamchuk, A., Norton, W., Miller, N., Nicolson, T., Braubach, O., … Schneider, H. (2013). Towards a comprehensive catalog of zebrafish behavior 1.0 and beyond. *Zebrafish Neuroscience Research Consortium, 10*(1), 70-86. https://doi.org/10.1089/zeb.2012.0861

Ko, I.-G., Kim, S.-E., & Kim, T.-W. (2013). Swimming exercise alleviates the symptoms of attention-deficit hyperactivity disorder in spontaneous hypertensive rats. *Molecular Medicine Reports, 8*(2), 393-400. https://doi.org/10.3892/mmr.2013.1531

Kozol, R. A., Cukier, H. N., Zou, B., Mayo, V., De Rubeis, S., Cai, G., Griswold, A. J., Whitehead, P. L., Haines, J. L., Gilbert, J. R., Cuccaro, M. L., Martin, E. R., Baker, J. D., Buxbaum, J. D., Pericak-Vance, M. A., & Dallman, J. E. (2015). Two knockdown models of the autism genes SYNGAP1 and SHANK3 in zebrafish produce similar behavioral phenotypes associated with embryonic disruptions of brain morphogenesis. *Human Molecular Genetics, 24*(14), 4006-4023. https://doi.org/10.1093/hmg/ddv138

Kumar, S., Mi, J., Zhang, O., Chang, B., Le, H., Khoshabeh, R., & Nguyen, T. (2021). Human-inspired camera: A novel camera system for computer vision. In *Proceedings of the 18th International SoC Design Conference* (pp. 29-30). IEEE. https://doi.org/10.1109/ISOCC53507.2021.9613914

Kocić, A., Aleksić, J., & Kocić, J. (2023). Uticaj "plivanja za bebe" na umetničko plivanje [The impact of "baby swimming" on artistic swimming]. In *Proceedings of the 2nd National Scientific Conference "Aesthetic Sports between Art and Sport–On the Paths of Choreographic Manuscripts"*.

Lawson, L. M., Lisk, C., Carlson, J., Priebe, M., Shaver, E., & Wilson, F. (2020). The feasibility of measuring heart rate of children with autism during swim lessons and potential health outcomes. *Therapeutic Recreation Journal, 54*(3), 259-275. https://doi.org/10.18666/TRJ-2020-V54-I3-10200

Lee, J., & Poreta, D. L. (2013). Enhancing motor skills of children with autism spectrum disorder: A pool-based approach. *Journal of Physical Education, Recreation and Dance, 84*(1), 41-45. https://doi.org/10.1080/07303084.2013.746154

Leite, H. R., Mourão, F., & Drumond, L. E. (2012). Swim training attenuates oxidative damage and promotes neuroprotection in cerebral cortical slices submitted to oxygen glucose deprivation. *Journal of Neurochemistry, 123*(2), 317-324. https://doi.org/10.1111/j.1471-4159.2012.07898.x

Leo, I., Leone, S., Dicataldo, R., Vivenzio, C., Cavallin, N., Taglioni, C., & Roch, M. (2022). A non-randomized pilot study on the benefits of baby swimming on motor development. *International Journal of Environmental Research and Public Health, 19*, Article 9262. https://doi.org/10.3390/ijerph19159262

Liu, C., Li, C., Hu, C., Wang, Y., Lin, J., Jiang, Y.-H., Li, Q., & Liu, X. X. (2018). CRISPR/Cas9-induced shank3b mutant zebrafish display autism-like behaviors. *Molecular Autism, 9*, Article 23. https://doi.org/10.1186/s13229-018-0204-x

Liu, C., Wang, Y., Deng, J., Lin, J., Hu, C., Li, Q., & Xu, X. (2021). Social deficits and repetitive behaviors are improved by early postnatal low-dose VPA intervention in a novel shank3-deficient zebrafish model. *Frontiers in Neuroscience, 15*. https://doi.org/10.3389/fnins.2021.682054

Mei, Y., Monteiro, P., & Zhou, Y. (2016). Adult restoration of Shank3 expression rescues selective autistic-like phenotypes. *Nature, 530*(7591), Article 481. https://doi.org/10.1038/nature16971

Meng, Y., Xu, D., Zhang, W., Meng, W., Lan, X. Y., Wang, X., Li, M., Zhang, X., Zhao, Y., Yang, H., Zhang, R., & Zhen, Z. (2022). Effect of early swimming on the behavior and striatal transcriptome of the Shank3 knockout rat model of autism. *Neuropsychiatric Disease and Treatment, 18*, 681-694. https://doi.org/10.2147/NDT.S357338

Meshalkina, D. A., Kizlyk, M. N., Kysil, E. V., Collier, A. D., Echevarria, D. J., Abreu, M. S., Barcellos, L. J., Song, C., Warnick, J. E., Kyzar, E. J., & Kalueff, A. V. (2018). Zebrafish models of autism spectrum disorder. *Experimental Neurology, 299*, 207-216. https://doi.org/10.1016/j.expneurol.2017.02.004

Ogi, A., Licitra, R., Naef, V., Marchese, M., Fronte, B., Gazzano, A., & Santorelli, F. M. (2021). Social preference tests in zebrafish: A systematic review. *Frontiers in Veterinary Science, 7*. https://doi.org/10.3389/fvets.2020.590057

Oliveira, R. F. (2013). Mind the fish: Zebrafish as a model in cognitive social neuroscience. *Frontiers in Neural Circuits, 7*. https://doi.org/10.3389/fncir.2013.00131

Pan, H., Lv, Z., & Liu, Z. Z. (2023). A fast alignment algorithm for posture measurement of autistic children in swimming using computer vision. In *Proceedings of the 2023 IEEE International Conference on Integrated Circuits and Communication Systems* (pp. 1-6). IEEE. https://doi.org/10.1109/ICICACS57338.2023.10099638

Pan, Y. C. (2010). Effects of water exercise swimming program on aquatic skills and social behaviors in children with autism spectrum disorders. *Autism, 14*(1), 9-28. https://doi.org/10.1177/1362361309339496

Pan, Y. C. (2011). The efficacy of an aquatic program on physical fitness and aquatic skills in children with and without autism spectrum disorders. *Research in Autism Spectrum Disorders, 5*, 657-665. https://doi.org/10.1016/j.rasd.2010.07.002

Peca, J., Feliciano, C., & Ting, J. T. (2011). Shank3 mutant mice display autistic-like behaviours and striatal dysfunction. *Nature, 472*(7344), 437-534. https://doi.org/10.1038/nature09965

Pereira, K. R. G., Valentini, N. C., Saccani, R., & De Azevedo, H. A. (2011). Influência de atividades aquáticas no desenvolvimento motor de bebês [Influence of aquatic activities on motor development in babies]. *Journal of Physical Education, 22*(2), 159-168. https://doi.org/10.4025/reveducfis.v22i2.9644

Piljak, A., & Kocić, A. (2022). The impact of "baby swimming" on the health and development of infants and babies. In *Proceedings of the XXI International Science Conference*.

Prupas, A., Harvey, W. J., & Benjamin, J. (2006). Early intervention aquatics a program for children with autism and their families. *Journal of Physical Education, Recreation & Dance, 77*(2), 46-51. https://doi.org/10.1080/07303084.2006.10597829

Rogers, L., Hemmeter, M. L., & Wolery, M. (2010). Using a constant time delay procedure to teach foundational swimming skills to children with autism. *Topics in Early Childhood Special Education, 30*(2), 102-111. https://doi.org/10.1177/0271121410369708

Roy, A., Roy, M., Deb, S., & Unwin, G. (2015). Are opioid antagonists effective in attenuating the core symptoms of autism spectrum conditions in children: A systematic review. *Journal of Intellectual Disability Research, 59*(3), 293-306. https://doi.org/10.1111/jir.12142

Santos, C., Burnay, C., Button, C., & Cordovil, R. (2023). Effects of exposure to formal aquatic activities on babies younger than 36 months: A systematic review. *International Journal of Environmental Research and Public Health, 20*(8), Article 5610. https://doi.org/10.3390/ijerph20085610

Sigmundsson, H., & Hopkins, B. (2009). Baby swimming: Exploring the effects of early intervention on subsequent motor abilities. *Child Care Health and Development, 36*(3), 428-430. https://doi.org/10.1111/j.1365-2214.2009.00932.x

Sigwalt, A. R., Budde, H., & Helmich, I. (2011). Molecular aspects involved in swimming exercise training reducing anhedonia in a rat model of depression. *Neuroscience, 192*, 661-674. https://doi.org/10.1016/j.neuroscience.2011.05.075

Stevanović, D. (2021). Neurorazvojni poremećaji u međunarodnoj klasifikaciji bolesti, 11 izdanje (MKB-11): Pregled [Neurodevelopmental disorders in the international classification of diseases, 11th edition (ICD-11): Overview]. *Engrami, 43*(1), 50-69. https://doi.org/10.5937/engrami43-32939

Vyas, K. (2021). *Data efficient analysis of human behavior by spatio-temporal pose generation and inference* [Master's thesis, Northeastern University].

Wang, W. T., Li, C. C., & Chen, Q. (2017). Striatopallidal dysfunction underlies repetitive behavior in Shank3-deficient model of autism. *Journal of Clinical Investigation, 127*(5), 1978-1990. https://doi.org/10.1172/JCI87997

Yanardag, M., Akmanoglu, N., & Yilmaz, I. (2013). The effectiveness of video prompting on teaching aquatic play skills for children with autism. *Disability and Rehabilitation, 35*(1), 47-56. https://doi.org/10.3109/09638288.2012.687030

Yilmaz, I., Konukman, F., Birkan, B., Ozen, A., Yandrag, M., & Camursoy, I. (2010). Effects of constant time delay procedure on the Halliwick's method of swimming rotation skills for children with autism. *Education and Training in Autism and Developmental Disabilities, 45*(1), 124-135.

Yilmaz, I., Yanardag, M., Birkan, B., & Bumin, G. (2004). Effects of swimming training on physical fitness and water orientation in autism. *Pediatrics International, 46*, 624-626. https://doi.org/10.1111/j.1442- 200x.2004.01937.x

Yoo, T., Cho, H., & Lee, J. (2018). GABA neuronal deletion of Shank3 exons 14-16 in mice suppresses striatal excitatory synaptic input and induces social and locomotor abnormalities. *Frontiers in Cellular Neuroscience, 12*. https://doi.org/10.3389/fncel.2018.00341

Zhu, M., Idikuda, V. K., & Wang, J. (2018). Shank3-deficient thalamocortical neurons show HCN channelopathy and alterations in intrinsic electrical properties. *Journal of Physiology, 596*(7), 1259-1276. https://doi.org/10.1113/JP275147