Published in final edited form as:

J Autism Dev Disord. 2020 January ; 50(1): 342–348. doi:10.1007/s10803-019-04224-5.

Accelerating motor skill acquisition for bicycle riding in children with ASD: A pilot study

Zoë Hawks¹, John N. Constantino^{2,3,4}, Claire Weichselbaum², Natasha Marrus^{2,4}

¹Department of Psychological & Brain Sciences, Washington University, St Louis, Missouri 63105, USA

²Department of Psychiatry, Washington University, St Louis, Missouri 63110, USA

³Department of Pediatrics, Washington University, St Louis, Missouri 63110, USA

⁴Intellectual and Developmental Disabilities Research Center, Washington University, St Louis, Missouri 63110, USA

Abstract

Motor impairment is common in autism spectrum disorder (ASD) and, as such, a potential target for interventions to improve adaptive functioning. This study investigated motor skill acquisition in children with ASD ($n = 15$, 12 males; ages 7 – 16 years) during iCan Bike Camp, a one-week, community-based intervention (5×75-minute sessions) to teach independent bicycle riding. After completing the camp's task-oriented, individualized training program, all participants demonstrated motor skill acquisition on the bicycle, and nine participants rode independently at least 70 feet. Exploratory analyses showed that motor coordination and social communication correlated with rates of skill acquisition. These findings indicate the feasibility and efficacy of brief, community-based motor interventions to teach bicycle riding—an important developmental skill supporting adaptive functioning—to children with ASD.

Corresponding author information: Natasha Marrus, Department of Psychiatry, Washington University in St. Louis School of Medicine, 660 S. Euclid Ave, St. Louis, MO 63110; natasha@wustl.edu.

Zoë Hawks: Department of Psychological & Brain Sciences, Washington University, St Louis, Missouri 63105, USA

John N. Constantino: Department of Psychiatry, Washington University, St Louis, Missouri 63110, USA; Department of Pediatrics, Washington University, St Louis, Missouri 63110, USA; Intellectual and Developmental Disabilities Research Center, Washington University, St Louis, Missouri 63110, USA

Claire Weichselbaum: Department of Psychiatry, Washington University, St Louis, Missouri 63110, USA

Natasha Marrus: Department of Psychiatry, Washington University, St Louis, Missouri 63110, USA; Intellectual and Developmental Disabilities Research Center, Washington University, St Louis, Missouri 63110, USA

Publisher's Disclaimer: This Author Accepted Manuscript is a PDF file of an unedited peer-reviewed manuscript that has been accepted for publication but has not been copyedited or corrected. The official version of record that is published in the journal is kept up to date and so may therefore differ from this version.

Conflict(s) of interest: ZH, CW, and NM declare that they have no conflict of interest. JNC receives royalties from Western Psychological Services for commercial distribution of the Social Responsiveness Scale-2.

Research involving human participants: All procedures performed in this study were in accordance with the ethical standards of the institutional research committee (Washington University School of Medicine IRB #201804135) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study. Specifically, participants and their parents provided verbal assent and written consent, respectively.

Keywords

Autism Spectrum Disorder (ASD); social communication; motor coordination; motor skill acquisition; adaptive function; bicycle riding

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by (1) deficits in social communication and interaction, including deficits in social-emotional reciprocity, nonverbal communication, and social motivation; and (2) restricted interests and repetitive behaviors (American Psychiatric Association, 2013). These core symptoms of ASD frequently interfere with adaptive functioning, which refers to the ability to use cognitive capacities to perform activities of daily living (Pugliese et al., 2015). Notably, adaptive functioning constitutes a major determinant of outcomes in ASD (Kanne et al., 2011).

In addition to core autistic symptoms, common “non-specific” co-occurring features of ASD may impact adaptive function. One increasingly recognized comorbidity is motor impairment. Evidence suggests that 87% of individuals with ASD also exhibit motor impairment(s) such as gross motor discoordination, fine motor discoordination, difficulties with imitation, and difficulties with praxis (Van Waelvelde, Oostra, Dewitte, & Vanden Broeck, 2010). These motor impairments often emerge during infancy prior to the onset of core autistic symptoms, persist across the lifespan, and correlate with the severity of autistic features (Bhat, Landa, & Galloway, 2011; Constantino, 2018; Van Waelvelde et al., 2010). Early motor abilities, in turn, are hypothesized to exert a cascading effect on social development by facilitating social interaction and learning, and prior work has identified relationships between early motor function and later social outcomes (see Leonard & Hill, 2014 for a review).

A growing body of research further indicates that some of the same genetic and neurobiological factors that predispose motor impairments in ASD may also predispose social communication deficits (Mostofsky & Ewen, 2011). With respect to genetics, damaging *de novo* mutations implicated in ASD have been linked to motor impairments (Buja et al., 2018), and results of a recent family study suggest that heritable factors underlying motor coordination may contribute to the causation of ASD itself (Mous, Jiang, Agrawal, & Constantino, 2017). With respect to neurobiology, damage to the cerebellum is associated not only with diminished motor coordination (e.g., Bower & Parsons, 2003), but also with diminished social and emotional abilities (e.g., Hoche, Guell, Sherman, Vangel, & Schmahmann, 2016). Thus, co-occurring motor impairments in ASD may reflect convergent developmental, neurobiological, and genetic mechanisms, with implications for clinical outcomes.

Due to its position at the intersection of social communication and adaptive function, motor impairment represents a promising therapeutic target in ASD. One specific motor skill important for adaptive function—independent bicycle riding—was the focus of the present study. Although independent bicycle riding is a commonly-acquired skill during typical development, it requires a high level of motor coordination (Mandich, Polatajko, & Rodger, 2003) and poses a significant challenge for many children with ASD (MacDonald et al.,

2012). Overcoming this challenge affords increased opportunities for exercise and socialization (Lang et al., 2010). Such opportunities are especially important for health and well-being in children with ASD, who commonly struggle to obtain regular exercise and engage with peers (Orsmond, Krauss, & Seltzer, 2004; Pitetti, Rendoff, Grover, & Beets, 2007; Todd, Reid, & Butler-Kisber, 2010).

The present study therefore investigated rates of motor skill acquisition and bicycle-riding outcomes in children with ASD during iCan Bike Camp, a community-based intervention designed to teach independent bicycle riding. Consistent with best-practice recommendations for motor interventions, and in contrast with normative “training-wheels to two-wheels” methods, iCan Bike Camp employed an individualized, task-oriented approach that prioritized enhanced functionality over normality in task performance (Smits-Engelsman et al., 2018). Prior research has explored physical characteristics (e.g., leg strength) that predict the success of bicycle-based interventions in children with developmental disorders (MacDonald et al., 2012), but rates of motor skill acquisition have not been examined, nor has a sample with severe ASD symptoms been studied¹.

In addition to evaluating the feasibility and efficacy of this program for children with ASD, we explored whether social communication and motor coordination (MC; defined as capabilities relating to controlled movements, fine motor activities, and gross motor activities) explained unique or overlapping variance in motor skill acquisition during camp. We hypothesized that (1) greater social communication deficits would predict reduced motor skill acquisition; (2) greater MC would predict improved motor skill acquisition; and, (3) social communication deficits and MC would explain overlapping variance in motor skill acquisition, given accumulating evidence for shared heritable and neurobiological factors underlying these constructs.

Methods

Data were collected at iCan Bike Camp, a one-week (five 75-minute sessions; one session per day) camp designed to teach independent bicycle riding. This annual event was advertised to local families of children with ASD through the non-profit organization Missouri Families for Effective Autism Treatment and cost \$150 to participate. Study recruitment occurred via email and on-site prior to camp. Participants and their parents provided verbal assent and written consent, respectively. All study procedures were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Participants diagnosed with ASD by a medical professional were included in analyses ($n = 15$; Table 1); three participants with other (non-ASD) neurodevelopmental disorders affecting motor function were excluded. Participants were not excluded on the basis of psychiatric comorbidities. Parent-reported skill level prior to camp indicated that some participants had familiarity riding tandem bicycles ($n = 4$) and/or bicycles with training wheels ($n = 8$). Only one parent reported attempts at independent riding.

¹ASD severity operationalized per Social Responsiveness Scale-2 age norms (Constantino & Gruber, 2012)

During camp, participants trained on specially-configured bicycles with variously-sized, tapered cylinders attached to the rear wheel for support (cf. Klein, McHugh, Harrington, Davis, & Lieberman, 2005; MacDonald et al., 2012; Ulrich, Burghardt, Lloyd, Tiernan, & Hornyak, 2011). Cylinders were interchangeable, allowing support to be adjusted according to an individual rider's ability to maintain balance and control (Klein et al., 2005). As participants demonstrated mastery on a given cylinder, they graduated to incrementally smaller cylinders and, ultimately, to standard two-wheeled bicycles. Mastery was assessed by a floor supervisor trained to evaluate campers' pedaling, posture, speed, and control. Two spotters jogged alongside each camper, providing verbal and nonverbal prompts and encouragement, as well as physical assistance as needed to support rider stability and prevent crashes. Physical assistance primarily involved steadying the bicycle by gripping an inverted L-shaped handle that extended from the back seat; spotters could also briefly guide the front handles or touch the rider. To enhance rapport and motivation, riders were typically paired with the same spotters each session, and riders were allowed breaks for frustration or fatigue. Sessions began indoors at a gymnasium and moved outdoors to a parking lot as skill-level progressed. Parents were present but not directly engaged in training.

Motor skill level was operationalized according to cylinder dimensions established in earlier research (Klein et al., 2005; MacDonald et al., 2012; Ulrich et al., 2011), and motor skill acquisition was indexed as the day-to-day change in motor skill level. Specifically, we used a staged classification system (0 – 5) in which low numbers corresponded to larger, more supportive cylinders (i.e., lower motor skill) and high numbers corresponded to smaller, less supportive cylinders (i.e., higher motor skill). The largest number (5) corresponded to the absence of cylindrical supports (i.e., a standard two-wheel bicycle). Stepwise progress from larger to smaller cylinders has been associated with attainment of independent bicycle riding (Klein et al., 2005). To meet study criteria for independent bicycle riding, participants were required to ride at least 70 feet without cylindrical supports or assistance from spotters. This distance approximates the length of most indoor iCan Bike Camp facilities and exceeds the distance a rider can maintain forward momentum solely from being pushed (personal communication, iCan Shine, Inc.).

Motor coordination (MC) and social communication were assessed on the first day of camp using parent-report measures. Parents completed the Developmental Coordination Disorder Questionnaire (DCDQ), a well-validated, 15-item scale designed to identify MC difficulties relating to controlled movement, fine motor activity, and gross motor activity among children and adolescents in general and clinical populations (Wilson et al., 2009). Lower DCDQ scores indicate decreased MC. Social communication deficits were assessed via parental ratings on the social communication and interaction (SCI) subscale from the Social Responsiveness Scale-2 (SRS-2), an extensively validated measure of quantitative autistic traits from preschool through adulthood (Constantino & Gruber, 2012). Scores on the SRS-2 are continuously distributed in the general population, differentiate levels of autistic symptoms, and exhibit temporal stability (Constantino & Gruber, 2012). Higher SCI scores indicate greater social impairment.

Primary analyses quantified both independent bicycle-riding and motor skill acquisition during camp. Exploratory analyses were conducted using Bayesian Multi-Level Modeling

(MLM) to examine MC and SCI as predictors of motor skill acquisition. Bayesian statistics incorporate background knowledge (i.e., priors) to improve model estimation. Associated probabilities represent the uncertainty in any event or hypothesis. Relative to frequentist (e.g., maximum likelihood) approaches, Bayesian statistics are more robust to small samples and guard against the over-interpretation of unlikely results (Van de Schoot et al., 2014). MLM is a modeling approach that accounts for shared variance in nested data. In the present study, days at camp were nested within participants.

Bayesian models were implemented in R using the package *rstanarm* (Goodrich, Gabry, Ali, & Brilleman, 2018) with four randomly initialized Markov chains ($n_{\text{iterations}} = 3000$, $n_{\text{warmup}} = 1000$) and weakly informative (default) priors. Prior to modeling, age, MC, and SCI were standardized. Intercept and slope (for time) were modeled separately for each individual to account for longitudinal dependencies. Trace plots indicated clear stationarity and good mixing, and numerical checks of sampling quality indicated convergence (i.e., $\hat{R} = 1.0$, Monte Carlo standard error = 0.0, and effective sample size > 2,000).

Results

Sample characteristics (Table 1) indicate that, consistent with ASD, participants displayed elevated autistic traits on the SRS-2 and low motor coordination on the DCDQ. At the end of camp, nine of 15 participants rode a two-wheel bicycle independently (i.e., without cylindrical supports or assistance from spotters) at least 70 feet. Among the 10 participants with prior bike-riding experience, five attained this level of independence; among the five participants without prior experience, four attained this level of independence. Importantly, all participants demonstrated motor skill acquisition ($_{\text{minimum}} = 3$ cylinders) during camp (Figure 1).

Results of statistical analyses are provided in Table 2. Credible intervals (CI) specify a range of values within which a given parameter is expected to occur at a given probability. If the 95% CI does not include zero, then there is at least a 95% probability that change to an independent variable predicts meaningful change in the associated dependent variable. In Models 1–3, characteristics related to general development (i.e., age) and academic achievement (i.e., grade level) failed to predict meaningful variance in motor skill acquisition. In contrast, training time (in days) was a strong predictor of motor skill acquisition ($\psi_{\psi4} = 1.21$, 95% CI = [1.10, 1.33]).

In Models 1 and 2, both SCI and MC emerged as important predictors of motor skill acquisition during camp. In Model 1, a one standard deviation increase in SCI (indicating increased social communication deficits) was associated with a 0.21 (95% CI = [−0.42, −0.01]) decrease in skill acquisition, controlling for covariates. This suggested that greater SCI was associated with reduced skill acquisition (Figure 2A). In Model 2, a one standard deviation increase in MC was associated with a 0.31 (95% CI = [0.11, 0.51]) increase in skill acquisition, controlling for covariates. This suggested that reduced MC was associated with reduced skill acquisition (Figure 2B). When SCI and MC were modeled together, SCI ($\mu = -0.07$, 95% CI = [−0.31, 0.16]) did not reliably explain variance above and beyond MC ($\mu = 0.27$, 95% CI = [0.02, 0.51]). Indicative of construct overlap, SCI and MC were strongly

correlated ($r = -.52$, $p < .05$; Figure 2C). Notwithstanding these predictors, *every participant* improved during the week of camp, underscoring the efficacy of iCan Bike Camp's highly individualized training program.

Discussion

Independent bicycle riding is a valuable skill that may improve adaptive function while encouraging autonomy, self-confidence, and new peer interactions among individuals with ASD. Unlike conventional training wheels, iCan Bike Camp utilized a task-oriented approach in which (1) motor demands incrementally increased as cylinder sizes incrementally decreased; (2) demands were titrated to individual ability, as evaluated by the floor supervisor; and (3) spotters facilitated progress through immediate verbal and physical feedback and support. The week-long format (five daily 75-minute sessions) allowed cumulative growth without overwhelming or fatiguing campers, as evidenced by steady motor skill acquisition and high attendance throughout camp. Thus, iCan Bike Camp's learning environment was optimized in comparison to "one-size-fits-all" training wheel approaches, which provide minimal scaffolding in the transition to independent riding, may reinforce anxiety related to sensations of instability, and often prove counterproductive for children with ASD (Burt, Porretta, & Klein, 2007; Klein et al., 2005).

From a research perspective, iCan Bike Camp afforded a unique opportunity to measure motor skill acquisition for a specific, complex motor task under naturalistic conditions. After approximately six hours of training, all participants exhibited motor skill acquisition, and nine of 15 participants were able to ride a two-wheel bicycle independently, a strong success considering the sample's elevated ASD severity and motor coordination impairment. These results represent functionally significant gains and demonstrate the feasibility of accelerating motor skill acquisition via focused intervention in children and adolescents with ASD. Future research may extend these results by investigating similarly supportive training for other motor skills throughout development (e.g., swimming, dancing; cf. iCan Shine, 2019), with promising implications for refining interventions for adaptive function in ASD.

Exploratory statistical analyses found that, in the present sample of children with ASD, greater core deficits in social communication and interaction (SCI) and lower motor coordination (MC) predicted reduced motor skill acquisition. SCI and MC were highly correlated, replicating prior studies (Constantino & Gruber, 2012; Constantino, 2018), and explained overlapping variance in motor skill acquisition. This latter finding suggests that both core (i.e., social) and non-core (i.e., motor) symptom domains, which are themselves neurobiologically linked (Mostofsky & Ewen, 2011), may represent therapeutic targets for improving adaptive function in ASD. Given that motor impairments may emerge before core ASD symptoms (Estes et al., 2015), the overlap could be consistent with a model whereby motor and social domains become progressively interrelated during development (Constantino, 2018; Hawks et al., 2018). Future studies characterizing developmental relationships among SCI and MC, as well as hypothetical third variables implicated in both functions (e.g., cerebellar mediated predictive learning; Van de Cruys, Evers, Hallen, & Eylen, 2014), may disambiguate these possibilities and guide the content and timing of interventions.

The present pilot study capitalized upon existing iCan Bike Camp infrastructure to obtain ecologically valid insights into real-world motor skill acquisition in ASD. This unique naturalistic design, while a major strength, entailed a small sample and precluded comparisons against children with other neurodevelopmental conditions. It also constrained measurement of physical (e.g., balance, muscular strength) and cognitive (e.g., IQ) factors that may be related to independent riding; although age and grade level were unrelated to motor skill acquisition (Table 2). Finally, we do not have data pertaining to skill maintenance or generalization to other useful daily activities. Thus, replications and extensions in larger populations are warranted to test the robustness and generalizability of the present findings. Despite limitations, results are promising. They indicate the feasibility and efficacy of community-based, personalized motor interventions for children with ASD, and contribute to growing evidence linking social impairment to reduced motor coordination in ASD (Buja et al., 2018; Mostofsky & Ewen, 2011).

Acknowledgements:

This work was funded by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number U54 HD087011 (the Intellectual and Developmental Disabilities Research Center at Washington University) and National Institute of Mental Health (K08 MH112891 to NM). We would like to thank the Bike Camp participants and their families, as well as the Missouri Families for Effective Autism Treatment (MO-FEAT), who hosted the camp, and the iCan Shine organization, who runs the camp. We would also like to thank Lauren Castelbaum, Jordan Albright, and Danielle Abrams for assistance with data collection.

References

- American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders. Arlington 10.1176/appi.books.9780890425596.744053
- Bhat AN, Landa RJ, & Galloway JC (2011). Current Perspectives on Motor Functioning in Infants, Children, and Adults With Autism Spectrum Disorders. *Physical Therapy*, 91(7), 1116–1129. 10.2522/ptj.20100294 [PubMed: 21546566]
- Bower JM, & Parsons L (2003). Rethinking the “Lesser Brain.” *Scientific American*, 289(2), 50–57.
- Buja A, Volfovsky N, Krieger AM, Lord C, Lash AE, Wigler M, & Iossifov I (2018). Damaging de novo mutations diminish motor skills in children on the autism spectrum. *Proceedings of the National Academy of Sciences*, 201715427 10.1073/pnas.1715427115
- Burt TL, Porretta DL, & Klein RE (2007). Use of Adapted Bicycles on the Learning of Conventional Cycling by Children with Mental Retardation. *Education and Training in Developmental Disabilities*, 42(September), 364–379.
- Constantino J, & Gruber C (2012). *Social Responsiveness Scale (SRS)*. Torrance, CA: WPS.
- Constantino JN (2018). Deconstructing autism: from unitary syndrome to contributory developmental endophenotypes. *International Review of Psychiatry*, 0(0), 1–7. 10.1080/09540261.2018.1433133
- Estes A, Zwaigenbaum L, Gu H, St. John T, Paterson S, Elison JT, ... Piven J (2015). Behavioral, cognitive, and adaptive development in infants with autism spectrum disorder in the first 2 years of life. *Journal of Neurodevelopmental Disorders*, 7(1), 1–10. 10.1186/s11689-015-9117-6 [PubMed: 25972975]
- Goodrich B, Gabry J, Ali I, & Brilleman S (2018). *rstanarm: Bayesian applied regression modeling via Stan*. R package version 2.17.4.
- Hawks ZW, Marrus N, Glowinski AL, & Constantino JN (2018). Early Origins of Autism Comorbidity: Neuropsychiatric Traits Correlated in Childhood Are Independent in Infancy. *Journal of Abnormal Child Psychology*. 10.1007/s10802-018-0410-1
- Hoche F, Guell X, Sherman JC, Vangel MG, & Schmahmann JD (2016). Cerebellar Contribution to Social Cognition. *Cerebellum*, 15(6), 732–743. 10.1007/s12311-015-0746-9 [PubMed: 26585120]

- iCan Shine. (2019). Who We Are. Retrieved from icanshine.org
- Kanne SM, Gerber AJ, Quirnbach LM, Sparrow SS, Cicchetti DV, & Saulnier CA (2011). The Role of Adaptive Behavior in Autism Spectrum Disorders: Implications for Functional Outcome. *Journal of Autism and Developmental Disorders*, 41(8), 1007–1018. 10.1007/s10803-010-1126-4 [PubMed: 21042872]
- Klein RE, McHugh E, Harrington SL, Davis T, & Lieberman LJ (2005). Adapted Bicycles for Teaching Riding Skills. *TEACHING Exceptional Children*, 37(6), 50–56. 10.1177/004005990503700606
- Lang R, Koegel LK, Ashbaugh K, Regester A, Ence W, & Smith W (2010). Physical exercise and individuals with autism spectrum disorders: A systematic review. *Research in Autism Spectrum Disorders*, 4(4), 565–576. 10.1016/j.rasd.2010.01.006
- Leonard HC, & Hill EL (2014). Review: The impact of motor development on typical and atypical social cognition and language: A systematic review. *Child and Adolescent Mental Health*, 19(3), 163–170. 10.1111/camh.12055
- MacDonald M, Esposito P, Hauck J, Jeong I, Hornyak J, Argento A, & Ulrich DA (2012). Bicycle training for youth with Down syndrome and autism spectrum disorders. *Focus on Autism and Other Developmental Disabilities*, 27(1), 12–21. 10.1177/1088357611428333
- Mandich AD, Polatajko HJ, & Rodger S (2003). Rites of passage: Understanding participation of children with developmental coordination disorder. *Human Movement Science*, 22(4–5), 583–595. 10.1016/j.humov.2003.09.011 [PubMed: 14624835]
- Mostofsky SH, & Ewen JB (2011). Altered connectivity and action model formation in autism is autism. *Neuroscientist*, 17(4), 437–448. 10.1177/1073858410392381 [PubMed: 21467306]
- Mous SE, Jiang A, Agrawal A, & Constantino JN (2017). Attention and motor deficits index non-specific background liabilities that predict autism recurrence in siblings. *Journal of Neurodevelopmental Disorders*, 9(1), 32. 10.1186/s11689-017-9212-y [PubMed: 28870164]
- Orsmond GI, Krauss MW, & Seltzer MM (2004). Peer relationships and social and recreational activities among adolescents and adults with autism. *Journal of Autism and Developmental Disorders*, 34(3), 245–256. 10.1023/B:JADD.0000029547.96610.df [PubMed: 15264493]
- Pitetti KH, Rendoff AD, Grover T, & Beets MW (2007). The efficacy of a 9-month treadmill walking program on the exercise capacity and weight reduction for adolescents with severe autism. *Journal of Autism and Developmental Disorders*, 37(6), 997–1006. 10.1007/s10803-006-0238-3 [PubMed: 17151799]
- Pugliese CE, Anthony L, Strang JF, Dudley K, Wallace GL, & Kenworthy L (2015). Increasing Adaptive Behavior Skill Deficits From Childhood to Adolescence in Autism Spectrum Disorder: Role of Executive Function. *Journal of Autism and Developmental Disorders*, 45(6), 1579–1587. 10.1007/s10803-014-2309-1 [PubMed: 25398602]
- Smits-Engelsman B, Vinçon S, Blank R, Quadrado VH, Polatajko H, & Wilson PH (2018). Evaluating the evidence for motor-based interventions in developmental coordination disorder: A systematic review and meta-analysis. *Research in Developmental Disabilities*, 74(February), 72–102. 10.1016/j.ridd.2018.01.002 [PubMed: 29413431]
- Todd T, Reid G, & Butler-Kisber L (2010). Cycling for students with ASD: Self-regulation promotes sustained physical activity. *Adapted Physical Activity Quarterly*, 27(3), 226–241. 10.1123/apaq.27.3.226 [PubMed: 20571157]
- Ulrich DA, Burghardt AR, Lloyd M, Tiernan C, & Hornyak JE (2011). Physical Activity Benefits of Learning to Ride a Two-Wheel Bicycle for Children With Down Syndrome: A Randomized Trial. *Physical Therapy*, 91(10), 1463–1477. 10.2522/ptj.20110061 [PubMed: 21852519]
- Van de Cruys, Van De S, Evers K, Van Der Hallen R, & Van Eylen L (2014). Precise Minds in Uncertain Worlds : Predictive Coding in Autism Precise Minds in Uncertain Worlds : Predictive Coding in Autism. *Psychological Review*, 1–36. 10.1037/a0037665
- Van de Schoot R, Kaplan D, Denissen J, Asendorpf JB, Neyer FJ, & van Aken MAG (2014). A Gentle Introduction to Bayesian Analysis: Applications to Developmental Research. *Child Development*, 85(3), 842–860. 10.1111/cdev.12169 [PubMed: 24116396]

- Van Waelvelde H, Oostra A, Dewitte G, & Vanden Broeck C (2010). Stability of motor problems in young children with or at risk of autism spectrum disorders, ADHD, and or developmental coordination disorder, (1). 10.1111/j.1469-8749.2009.03606.x
- Wilson BN, Crawford SG, Green D, Roberts G, Aylott A, & Kaplan BJ (2009). Psychometric properties of the revised developmental coordination disorder questionnaire. *Physical and Occupational Therapy in Pediatrics*, 29(2), 182–202. 10.1080/01942630902784761 [PubMed: 19401931]

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1.

At the start of camp, all participants were outfitted on bicycles with the largest, most supportive cylinders (i.e., level 0). By the end of camp, nine of 15 participants rode a two-wheel bicycle independently (solid lines). Among the 10 participants with prior bike-riding experience (orange lines), five attained this level of independence; among the five participants without prior experience (green lines), four attained this level of independence. All participants demonstrated motor skill acquisition (*minimum* = 3 cylinders).

Figure 2.

Motor skill acquisition was operationalized using an interval scale (0 – 5), with larger numbers corresponding to greater skill acquisition (i.e., smaller cylindrical supports). In (A) and (B), motor skill acquisition is plotted as a function of time elapsed in Bike Camp. (A) Lines depict motor skill acquisition in groups with low (long dash), average (solid line), or high (short dash) levels of social communication and interaction (SCI). High SCI (i.e., high social deficit) was associated with reduced skill acquisition during camp. (B) Lines represent groups with low (long dash), average (solid line), or high (short dash) levels of motor coordination (MC). Low MC was associated with reduced skill acquisition during camp. (C) As SCI increases, MC decreases ($r = -0.52$). SCI and MC were assessed on Day 1 of Bike Camp.

Table 1.**iCan Bike Camp sample characteristics**

	Count (N)	Percent (%)
Gender		
Male	12	80
Female	3	20
Race		
White	11	73
Black	1	7
Multiracial	3	20
Ethnicity		
Not Hispanic or Latino	15	100
ASD severity *		
Mild	0	0
Moderate	0	0
Severe	15	100
DCDQ suspected **	14	93
	Mean (SD)	Range
Age (in years)	10.8 (2.54)	7 – 16
Grade level	2.3 (0.8)	1 – 3
SRS-2		
SRS Total	153.3 (20.6)	126 – 195
SCI	122.5 (15.8)	97 – 151
RRB	30.8 (6.4)	23 – 44
DCDQ		
Total	37.5 (11.8)	23 – 65
Movement control	15.8 (5.0)	9 – 26
Fine motor	9.8 (4.8)	4 – 19
General coordination	11.9 (4.1)	5 – 20

Notes: DCD = developmental coordination disorder; SD = standard deviation; SRS = Social Responsiveness Scale; SCI = social communication and interaction; RRB = restricted interests and repetitive behaviors; DCDQ = Development Coordination Disorder Questionnaire.

* *ASD severity* derived from SRS-2 age and gender norms in the general population where, for raw scores, mean (SD) = 34 (26) for males and 29 (24) for females. Severity ranges for males and females, respectively, are as follows: Mild = 58 – 72 and 52 – 65; Moderate = 73 – 97 and 66 – 89; and Severe = 97+ and 90+.

** *DCD suspected* derived from DCDQ age norms, where mean (SD) = 65.9 (12.6) and lower scores indicate greater impairment.

Table 2.

Results of Bayesian analyses examining the effects of age, gender, grade level, training, SCI (models 1, 3), and MC (models 2, 3) on motor skill acquisition. Age, SCI, and MC were standardized prior to analyses. Rows are bolded if 95% CI excludes zero.

	Parameter	Mean ($\mu\beta$)	SD ($\sigma^2\beta$)	95% CI	N _{effective}
Model 1	Intercept	-1.21	0.36	[-1.84, -0.42]	6445
	Age	-0.07	0.13	[-0.31, 0.18]	4154
	Gender	0.60	0.38	[-0.21, 1.30]	2579
	Grade Level	-0.08	0.18	[-0.41, 0.30]	2719
	Training (days)	1.21	0.06	[1.10, 1.33]	6247
	SCI	-0.21	0.10	[-0.42, -0.01]	5578
Model 2	Intercept	-0.84	0.32	[-1.49, -0.22]	7694
	Age	-0.13	0.12	[-0.37, 0.09]	4096
	Gender	0.28	0.38	[-0.53, 0.96]	2531
	Grade Level	-0.09	0.16	[-0.38, 0.26]	2910
	Training (days)	1.21	0.05	[1.10, 1.32]	7932
	MC	0.31	0.10	[0.11, 0.51]	5551
Model 3	Intercept	-0.91	0.35	[-1.60, -0.23]	6245
	Age	-0.12	0.12	[-0.35, 0.12]	3977
	Gender	0.30	0.37	[-0.49, 0.99]	2815
	Grade Level	-0.07	0.16	[-0.36, 0.27]	2903
	Training (days)	1.21	0.05	[1.11, 1.32]	7757
	SCI	-0.07	0.12	[-0.31, 0.16]	4567
	MC	0.27	0.12	[0.02, 0.51]	4539

Notes: SD = standard deviation, CI = credible interval, N_{effective} = effective sample size