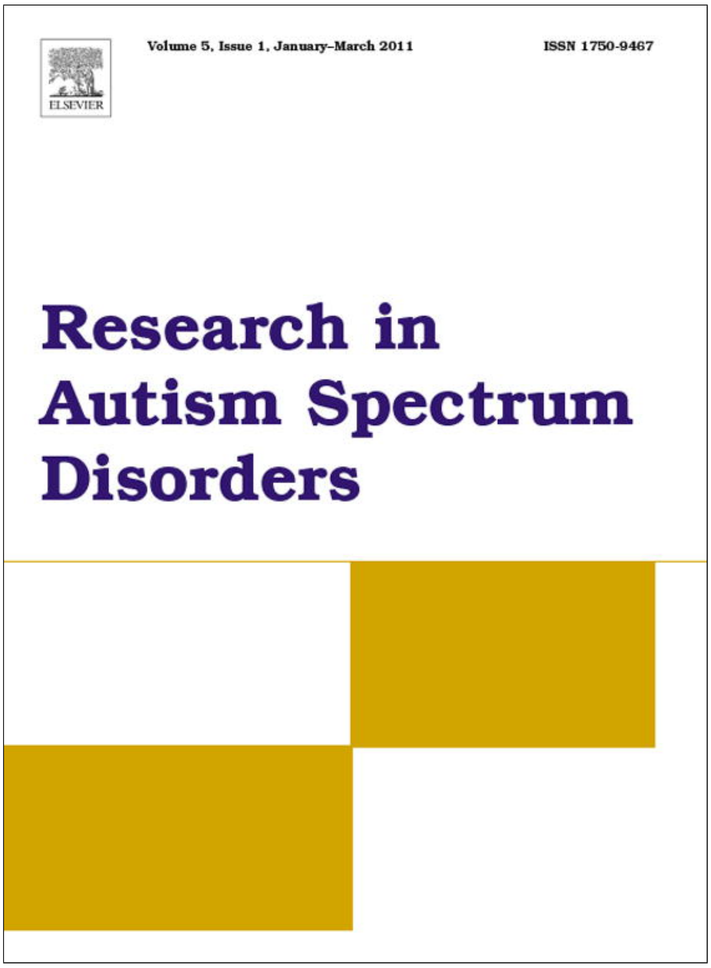

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Review

Effects of physical exercise on Autism Spectrum Disorders: A meta-analysis

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ABSTRACT

It is generally agreed that regular physical exercise promotes physical and mental health, but what are the benefits in people with Autism Spectrum Disorders (ASD)? This meta-analysis evaluates 16 behavioural studies reporting on a total of 133 children and adults with various variants of the syndrome who were offered structured physical activities either in an individual or a group context. The effects on social and motor deficiencies, two of the three primary symptom clusters of ASD, were normalized to afford a quantitative evaluation. Results pertaining to communication deficits were insufficient to permit classification. All activity programmes yielded significant progress on the measures assessed, but the individual programmes elicited significantly more improvement than the group interventions in the motor and, more surprisingly, also in the social domain. Although overall sample sizes were small, the combined results do permit the tentative conclusion that in terms of motor performance and social skills children and adults with ASD benefit most from individual exercise interventions. Further research of the impact of individual and group interventions on communication deficits in particular as well as studies gauging the extent to which exercise effects depend on ASD symptom severity are warranted.

Contents

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1. Introduction

1.1. Autism Spectrum Disorders

With an overall prevalence of 0.3–1.0% Autism Spectrum Disorders (ASD), previously also referred to as Pervasive Developmental Disorders (PDD), cover a wide range of neuropsychological conditions that affect both individual and social functioning (Vandereijcken, Hoogduin, & Emmelkamp, 2006). In the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) ASD includes classic autism, Asperger's syndrome, Rett's disorder, Childhood Disintegrative Disorder, and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS; American Psychiatric Association [APA], 2000). Although the clinical manifestations strongly differ per individual and age group (Vandereijcken, Hoogduin, & Emmelkamp, 2008), people diagnosed with ASD primarily display symptoms in three areas, i.e., deficiencies in social interaction, communication skills and motor performance (APA, 2000).

The difficulties with social interactions that people with ASD experience mainly pertain to a lack of understanding the behaviour of others (Vandereijcken et al., 2008) resulting from an inability to adequately interpret, consider or react to the social and emotional signals of others as communicated through eye contact and facial expressions. Generally, such deficiencies in non-verbal communication skills are referred to as a lack of "theory of mind", which implies a limited capacity to take note of, and understand, the feelings, plans and intentions of others (Vandereijcken et al., 2008). Reduced social skills also lead to a diminished imitation of the behaviour of parents, negatively affecting interactions (both communications and bonds) with caregivers and peers. According to Vandereijcken et al. (2008), nearly half of all autistic children fail to develop proper, verbal language skills and therefore remain mutistic. In others, the language development is delayed and displays various abnormalities. The third area in which people with ASD show problems is the domain of motor skills. Here, limited motor coordination, deficiencies in fine and gross motor functioning (Pan, Tsai, & Chu, 2009; Emck, Bosscher, van Wieringen, Doreleijers, & Beek, 2011), and repetitive, stereotypical movements, are common. Examples of the latter symptoms are hand waving when excited or extraordinary postures in stressful situations (Vandereijcken et al., 2008). Additional problems in maintaining balance and motion planning are also seen (Vernazza-Martin et al., 2005).

The range of symptoms that people with ASD may display necessitates that treatments address multiple deficiencies simultaneously, while being tailored to individual needs, which makes knowledge of ASD-specific interventions that have an overall positive impact indispensable. Before we describe the potential, beneficial effects of physical exercise and analyse the effects reported, we will first outline the aims of standard treatments of ASD (see e.g. Clark, Tuesday-Heathfield, Olympia, & Jenson, 2006; Delano, 2007).

1.2. Standard treatment of ASD

ASD treatment is typically aimed at stimulating cognition, language and social development while trying to suppress or eliminate maladaptive behavioural patterns such as rigidity and stereotypical movements (Koenig et al., 2010; Vandereijcken et al., 2006). Treatment further often addresses secondary symptoms such as hyperactivity, aggression, "fits of rage" and sudden mood changes. Recent research has shown that the standard treatment of ASD is reasonably effective for each of the three primary problem areas (Vismara & Rogers, 2010) and sometimes even improvements outside these primary symptom clusters are reported. Early group interventions have, for example, been shown to improve the intelligence level of children with ASD (Mayes & Calhoun, 2003). But do sport activities contribute to or enhance standard treatment outcomes? And if so, how?

1.3. Physical exercise and ASD

Despite the relative success of the standard treatments of ASD, the last two decades the interest in the potentially beneficial effects of physical exercise has grown. Systematic research in this area is nevertheless still relatively scarce and mostly based on small participant groups. The overall picture that emerged from the available results up until 1998 is that physical exercise not only improves the physical condition but also reduces the maladaptive behavioural patterns of people with ASD (Lancioni & O'Reilly, 1998).

Comparing typically developing children with children with ASD, Pan (2008) concludes that, overall, the latter group shows less activity. Also Hildebrandt, Chorus, and Stubbe (2010) stated that people with ASD constitute a special risk group because of their sedentary lifestyle, given that this increases the risks of heart disease, diabetes and obesity (World Health Organization [WHO], 2002). Since physical exercise has proven to be an effective means to prevent these problems in the general population, it is likely to also be effective in the ASD population. Pitetti, Rendoff, Grover, and Beets (2007) indeed showed that a walking programme not only improved the physical condition but also reduced the BMI index of ten adolescents with severe autism.

More importantly, as to the assumed beneficial effects on the three primary problem domains of ASD (Massion, 2006) it was found that, apart from improving balance and flexibility (Yilmaz, Yanardag, Birkan, & Bumin, 2004) aerobic exercise also reduced the stereotypical behavioural patterns of children with ASD (Elliot, Dobbin, Rose, & Soper, 1994; Yilmaz et al., 2004), as well as their self-stimulation behaviours (Powers, Thibadeau, & Rose, 1992). Other studies reported positive effects on social behaviour (Pan, 2010), communication skills (Hameury et al., 2010), academic engagement (Nicholson, Kehle, Bray, & van Heest, 2011), and sensory skills (Bass, Duchowny, & Llabre, 2009).

In sum, a global screening of the relevant literature suggests that physical exercise is a sensible approach to addressing a variety of problems associated with ASD. But does the existing literature support this conclusion quantitatively? And can we perhaps derive more refined recommendations from the findings regarding the type of sport and exercise interventions that are most suitable in the treatment of ASD?

1.4. Sport and exercise: individual versus group intervention

Regrettably, there are as yet no ASD studies that have systematically compared the effects of physical exercise in terms of individual and group interventions. By categorizing the relevant studies in our meta-analysis into individual and group interventions, we try to fill this gap.

One of the advantages of treating people with ASD individually is the possibility of tailoring the programme to the specific needs of the individual (Schultheis, Boswell, & Decker, 2000). Moreover, individual interventions may prevent people with ASD from feeling misunderstood by group members (Pan, 2009), since difficulties in non-verbal communication are bound to result in communication problems with teammates or opponents (Breedveld, Bruining, Dorsselaer, Mombarg, & Nootebos, 2010). Furthermore, unpredictable events during group sport activities tend to increase stress levels considerably. Although individual approaches avoid all these adverse effects, particularly for people with ASD group interventions may also have advantages. In team sports players support each other (Lox, Martin, & Petruzzello, 2010) and group activities facilitate social behaviour and communication skills, as Walker, Barry, and Bader (2010) showed: after attending a ‘‘Summer Treatment Camp’’ for four weeks the social and communication skills of children with ASD had improved.

Based on the reported effects of physical exercise in ASD described above, we expected our meta-analysis to show individual interventions to primarily improve motor skills and group interventions to foster social and communication skills. To test our hypotheses, we collected relevant scientific publications from the last twenty years and categorized the studies according to (a) the type of exercise intervention being investigated, i.e., individual versus group interventions and (b) the primary symptom area in which the effects of exercise were quantified. However, as our search yielded too few studies that had looked into the separate effects on communication skills, we could only differentiate between the reported effects on motor and social skills.

2. Method

2.1. Search procedure

Our meta-analysis was conducted in accordance with the guidelines for a systematic literature reviews in the health sciences as formulated by Bambra (2011). The search covered three electronic databases available at the Radboud University Nijmegen, The Netherlands, viz., Web of Science, PiCarta and PsycINFO. In the searches the following keywords were used: ‘‘Pervasive Developmental Disorders’’, ‘‘autism’’, ‘‘ASD/Autism Spectrum Disorder’’, ‘‘ADHD’’, ‘‘conduct disorder’’, ‘‘Asperger’’, ‘‘PDD-NOS’’ We paired these terms with ‘‘sport’’, ‘‘exercise’’, ‘‘physical exercise’’, ‘‘physical activity’’, ‘‘aerobic’’, ‘‘fitness’’, ‘‘swimming’’, ‘‘walk’’, ‘‘jogging’’, ‘‘group exercise’’. We looked for further pertinent articles using the generally accessible websites of ScienceDirect, SpringerLink, SAGE journals online, WILEY online library and Google Scholar. The Web of Science ‘‘related articles’’ option was exploited to identify any additional articles relevant to our field of interest.

2.2. Inclusion criteria

To be included in our meta-analysis, studies had to meet the following four criteria: (1) studies needed to have been published between 1991 and 2011; (2) they had to include children or adults with an ASD diagnosis (American Psychiatric Association, 2000); (3) the interventions described had to involve some kind of physical exercise; and finally, (4) the behavioural effects attributed to the interventions needed to be quantitative such that they could be transformed into percentages reflecting relative behavioural change. The search yielded a total of 16 studies meeting all four inclusion criteria.

2.3. Categorization of studies

We divided the studies that met our inclusion criteria into two categories: ‘‘individual’’ and ‘‘group’’. Interventions involving only one person with ASD were classified as ‘‘individual’’. Note that in this category more than one therapist could be interacting with the participant. Studies in the ‘‘group’’ category all described programmes involving two or more participants. Here, the participants were not required to communicate during the intervention, but they did need to be aware that they engaged in the physical activities together with others. Of the 16 relevant studies, half described an individual and the other half group-based exercise interventions.

2.4. Participants

All the participants in the experimental groups of the 16 selected studies were diagnosed with ASD in accordance with the criteria of the DSM-IV (American Psychiatric Association, 2000). Several studies involved a control group. Collectively, 133

Table 1
Overview of the studies included in the meta-analysis.

Study	Type of Intervention	Domain	Intervention content	ASD participants	Results
Allison, Basile, and MacDonald (1991)	Individual (case study)	Aggressive behaviour	Daily 20-min jogs during two 2-week intervals	One 24-year-old man with autism	Staff-rated aggressive behaviour was reduced (baseline $M = 2–0.36$) following jogging, with a two-tailed t test indicating that exercise had significantly decreased aggression ($t = 3.03$, $p > .01$)
Bass et al. (2009)	Group	Social responsiveness and sensory skills	12 weekly 1-h therapeutic horseback rides	19 participants in the experimental condition; 2 girls and 17 boys aged 5–10 years ($M = 6.95$ year); autism (DSM-IV).	Scales were parent-rated. Sensory profile overall score ($F(1,31) = 10.98$, $p = .002$, $n^2 = .26$). The experimental group showed significantly increased pre-to-post-test scores ($t(18) = -7.29$, $p < .01$, $d = -.059$), with significant interaction effects for four of the five subscales: sensory seeking ($F(1,30) = 17.09$, $p < .01$, $n^2 = .40$), attention and distractibility ($F(1,29) = 19.17$, $p < .01$, $n^2 = .40$), sensory sensitivity ($F(1,31) = 31.01$, $p < .01$, $n^2 = .50$), and sedentary ($F(1,31) = 18.59$, $p \leq .01$, $n^2 = .375$). Treatment effects were statistically significant for the four subscales sensory seeking ($t(18) = 4.85$, $p < .001$), inattention/ distractibility ($t(17) = 5.19$, $p < .001$), sensory sensitivity ($t(18) = 6.20$, $p < .001$), and sedentary ($t(18) = 4.93$, $p < .001$). Social response scale overall score was significant for the experimental group ($F(1,20) = 4.92$, $p = .038$, $n^2 = .20$), as the follow-up scores ($t(10) = 2.87$, $p = .017$, $d = .66$). One of the three subscales was significant: social motivation ($F(1,25) = 4.80$, $p = .038$, $n^2 = .161$). Pre-to-post change was statistically significant for the experimental group ($t(13) = 3.93$, $p < .003$)
Celiberti, Bobo, Kelly, Harris, and Handleman (1997)	Individual (case study)	Self-stimulation behaviour	Three 6-min jogs alternated with three 6-min walks as control condition per week during three weeks	1 child, 5 years and 9 months old, autism (DSM-III)	Observer-rated physical self-stimulation had decreased following jogging (31%). A reduction in disruptive behaviour was observed in 50% of the sessions. Walking had no effects. The greatest suppression of physical self-stimulation occurred during the first 10 min after a jogging routine, after which a gradual increase in self-stimulation was observed
Elliot et al. (1994)	Group (groups of 3)	Maladaptive and stereotypic behaviours	20-min general motor training (bike riding, stair stepping, weight lifting or walking) and vigorous, aerobic exercise (jogging)	3 men and 3 women with ages ranging from 22.8 to 41.3 years ($M = 30.8$ year); autism (DSM-III)	Maladaptive and stereotypic behaviours had decreased significantly following jogging ($x^2(1) = 11.568$, $p < .001$). General motor training showed no significant effects ($x^2(1) = 1.672$, $p < .30$) nor did a non-exercise condition ($x^2(1) = 3.522$, $p < .10$). Following aerobic exercise, over 57% of the maladaptive and 65% of the stereotypic behaviour patterns showed improvement
Fragala-Pinkham, Haley, and O'Neil (2008)	Group (together with 10 children with other disabilities)	Cardiorespiratory endurance, muscle strength, motor skills	14 weeks of 30–50 min aquatic exercising	6 boys, aged 8–10 years; 3 with autism and 3 with PDD-NOS	Cardiorespiratory endurance yielded a significant ($F = 231.7$; df 1; $p < .001$; average effect size ES = .67). Muscle strength and motor skills showed no significant results
García-Villamisar and Dattilo (2010)	Group	Stress and Quality of Life	1 year leisure activities	37 participants (22 male and 15 female), ages ranging from 17 to 39 years ($M = 31.49$ year); autism and Asperger's syndrome	Stress had significantly decreased following the leisure programme ($F(1,69) = 22.42$, $p < .001$). Quality of Life had improved: post-test total scores were significant ($F(1,69) = 44.14$, $p < .001$), as were two of the four QoL subscales, i.e., satisfaction ($F(1,69) = 134.86$, $p < .001$) and competence-productivity ($F(1,69) = 22.43$, $p < .001$). Social integration and empowerment/independence showed no significant improvement

Table 1 (*Continued*)

Study	Type of Intervention	Domain	Intervention content	ASD participants	Results
Hameury et al. (2010)	Individual	Exercise adjustment and control systems (attention, perception, association, intention, tonus, motor adjustment, imitation, emotion, contact, communication)	1 h equine-assisted therapy	6 children, aged 5–7 years; autism	The children showed 52% improvement on the EFC total score; improvement rates per aspect assessed were: attention (22%), perception 32%, tonus 46%, motor adjustment 86%, imitation 60%, emotion 16%, contact 37%, and communication 24%. Their ECA total scores showed 18% improvement; improvement rates per aspect tested: perception 86%, tonus 65%, motor adjustment 95%, imitation 64%, emotion 82%, contact 71% and communication 65%
Lochbaum and Crews (2003)	Individual	Aerobic fitness or muscle strength training	Stationary cycling or weight lifting (18 training sessions)	5 participants; 3 in the aerobics condition, aged 16, 20 and 21 years, 2 in the strength-training condition, aged 16 and 17 years; autism	Aerobic fitness increased between 33% and 50% over the 18 sessions, while muscular strength training showed improvements ranging from 12% to 47%. The percentage change was greater for aerobic fitness than for muscular strength
Nicholson et al. (2011)	Group (together with healthy same-age peers)	Academic engagement time	2 weeks, three times per week 12-min jogs	4 children, aged 9 years, 2 with high- functioning autism and 2 with Asperger's syndrome	Academic engagement time increased during the physical exercise. Student 1 showed a significant increase in total engagement time in the treatment ($M = 88.29$; ES = −0.7) and follow-up condition ($M = 87.1$; ES = −0.6) compared to the baseline ($M = 82.16$). Compared to baseline ($M = 47.61$) he was significantly more active: post-treatment ($M = 66.66$; ES = −2.6) and follow-up ($M = 66.68$; ES = −2.6) and significantly less passive ($M = 21.52$; ES = 1.3 and $M = 20.36$; ES = 1.4, respectively) compared to baseline ($M = 34.58$). The data suggest that the improvement in academic engagement continued into the follow-up phase. Student 2 was significantly more engaged during the treatment ($M = 84.3$; ES = −1.5), and at post-treatment assessment more active ($M = 52.17$; ES = −1.5) and less passive ($M = 32.2$; ES = 1.1). Follow-up showed reductions relative to baseline level ($M = 78.12$; $M = 30.47$; $M = 47.6$) in total engagement time ($M = 76.94$; ES = 0.3), active engagement ($M = 27.24$; ES = 0.2) and passive engagement ($M = 49.7$; ES = −0.15). Student 3 showed a significant increase in total engagement time ($M = 74.03$; ES = −1.02) and active engagement ($M = 46.8$; ES = −0.9) in the treatment condition compared to baseline measures ($M = 64.39$; $M = 32.39$). Passive engagement time was non-significant ($M = 27.22$; ES = 0.3) compared to baseline ($M = 31.94$). The small values for total engagement time ($M = 67.18$; ES = −0.3), active engagement ($M = 31.2$; ES = 0.07) and passive engagement ($M = 35.98$; ES–0.25) during the follow-up period suggest that the student had returned to baseline level. Student 4 showed a significant increase in total engagement time ($M = 69.32$; ES = −0.9) and passive engagement ($M = 27.28$; ES = −0.8) in the treatment condition compared to baseline ($M = 61.11$; $M = 15.84$). Active engagement time was non-significant ($M = 41.92$; ES = 0.2) compared to the baseline ($M = 45.24$). Follow-up was significant for active engagement ($M = 23.8$; ES = 1.05) and passive engagement ($M = 39.5$; ES = −1.6) compared to baseline level. Only total engagement time was non-significant ($M = 63.3$; ES = −0.2)
Pan (2010)	Group (2:1 ratio)	Aquatic skills and social behaviour	10 weeks 90 min of aquatic exercising	16 boys aged 6–9 years ($M = 7.27/7.20$ year), 8 with high functioning autism and 8 with Asperger's syndrome	Significant improvement was recorded for one of the two groups on aquatic skills ($t = 14.47$, df = 7, $p < 0.01$), which also showed a significant reduction in antisocial behaviour ($t = -7.88$, df = 7, $p < 0.01$; $t = 6.24$, df = 7, $p < 0.01$)

Pan (2011)	Group (two groups)	Physical fitness and aquatic skills	10 weeks 60 min of aquatic exercising	15 children, aged 7–12 years (M = 9.31/8.75 year), high functioning autism and Asperger's syndrome	All children showed significant improvements on muscular strength/endurance (Cohen's d = 1.20), flexibility (Cohen's d = 2.83), cardiovascular fitness (Cohen's d = 6.14), and all stages of aquatic skills (Cohen's d = 5.71–47.62)
Pitetti et al. (2007)	Individual	Fitness	9 months treadmill walking	5 adolescents, 3 male and 2 female, 14–18 years (M = 16.6 year), severe autism	After the programme, the participants showed a significant reduction in BMI ($t(4) = 3.23$, $p = .016$), the relative percentage in BMI reduced from the baseline with a minimum of 2.8–17.2%. Weight showed a non-significant reduction ($t(4) = 1.904$, $p = .065$)
Rogers, Hemmeter, and Wolery (2010)	Individual (1:1 ratio)	Motor/swimming skills (flutter kick, front-crawl arm strokes, head turning to the side)	Swimming, 45–60 min.	3 boys; 4, 4 and 5 years of age; autism and PDD-NOS	The boys learned three new swimming skills. Boy 1 and boy 2 required 8 sessions to master the first skill, but required 6 sessions (the minimum number) for each of the two other skills. Boy 3 mastered all three skills within 6 sessions
Rosenthal-Malek and Mitchell (1997)	Individual	Self-stimulation behaviour and academic performance (academic responding and tasks completed)	20-min jogs	5 boys, aged 14–15 years, autism	Self-stimulatory behaviour had reduced in all five boys following exercise in both conditions (academic condition $t(4) = 4.26$, $p \leq .01$ and workshop condition $t(4) = 1.46$, $\leq .001$). Work-related performance had improved: After jogging correct academic responding (academic condition: $t(4) = 2.83$, $p < .05$) and the number of completed tasks (workshop condition: $t(4) = 4.71$, $p < .01$) had increased significantly
Todd and Reid (2006)	Group (participants engaged in activities at the same time and location)	Physical activity	6 months of outdoor physical activity (30 min. snowshoeing/ jogging/walking)	3 adolescents, aged 15, 16 and 20 years, autism (DSM-IV)	All three participants increased the distance they walked/jogged over the course of the programme (1.26 km, 1.14 km and 0.83 km) while reinforcers were decreased
Yilmaz et al. (2004)	Individual (case study)	Autistic behaviour and physical fitness	10 weeks swim training, 3×60 min per week	1 child, 9 years of age, with autism	Improvements were seen in balance, agility, speed, power scores, hand grip, lower and upper extremity muscle strength, flexibility and cardiovascular fitness. Autistic/stereotype behaviour had also changed: 1-h observations showed "swinging" to have reduced from 7 to 5 min, "spinning" from 2 to 0 min, and echolalia from 4 to 2 min

Table 2
Improvement (in percentages) per study/intervention, symptom domain and variables assessed, with details on concurrent treatment where available.

Study	% overall improvement	% improvement by domain	% improvement by variable	Concomitant medication and/or treatment
Allison et al. (1991)	Study: 82	Social interaction: 82	Aggressive behaviour: 82	No information
Bass et al. (2009)	Average 16.47	Motor function: 12.07 Social interaction: 20.71	*Sensory profile*: 13.38 Sensory seeking: 6.16 Inattention/distractibility: 28.57 Sensory sensitivity: 9.55 Sedentary: 18.52 Fine motor/perception: 5.62 *Social response scale*: 14.32 Social cognition: 22.6 Social awareness: 18.18 Social motivation: 27.75	Almost all participants had received conventional therapies
Celiberti et al. (1997)	Average: 31.82	Motor function: 31.82	Physical self-stimulation behaviour: 30.51 Visual self-stimulation behaviour: 12.31 "Out of seat" behaviour: 52.63	No information
Elliot et al. (1994)	Average 61	Motor function: 61	Following aerobic exercise: maladaptive behaviours: 57 stereotypic behaviours: 65	No information
Fragala-Pinkham et al. (2008)	Muscle strength: 3.24 Motor skills: 0.76 Average 2.5	Motor function: 2.5	*Cardiorespiratory endurance* Half mile: 2.31 *Muscle strength* Hip abductors: 8.94 Knee extensors: 0.23 Knee flexors: 4.98 Ankle plantar flexors: 1.18 Modified curl-up: 0.86 *Motor skills* FTS test: 1.02 M-PEDI: 0.49	All children received some level of additional therapy but the frequency and intensity of the services did not change during the study period. Also, several of the children were taking medication during the study period, but the type and dosage remained unchanged
García-Villamisar and Dattilo (2010)	Stress: 9.51 Quality of Life: 27.47 Average: 18.49	Rest category: 18.49	*Stress – total score*: 9.51 *Quality of Life* total score: 25.76 QoL – empowerment/independence: 9.15 QoL – satisfaction: 44.08 QoL – competence/productivity: 48.95 QoL – social/integration: 9.4	No information
Hameury et al. (2010)	Average: 59	Motor function: 80 Social function: 79.67 Communication: 64.5	*Autistic behaviour:* *EFC* Total: 52 Perception: 86 Tonus: 65 Motor function: 95 Imitation: 64 Emotion: 82 Contact: 71 Communication: 65 *ECA* Total: 2 Frequentation autistic behaviour: 8	No information

Lochbaum and Crews (2003)	Aerobic fitness: average 38.67 MST: average 26 Study average 32.34	Motor function: 32.34	*Aerobic fitness:* Participant 1: 33 Participant 2: 50 Participant 3: 33 *Muscular strength training* (Bench, low row and leg press): Participant 1: 19, 47 and 29 Participant 2: 28, 21 and 12	Participants were unmedicated
Nicholson et al. (2011)	Active engagement time: average 37.02 Passive engagement time: average −2.95 Total engagement time: average 11	Rest category: 11	*Academic engagement time* (total, active and passive time): Participant 1: 7.46, 40, 37.77 Participant 2: 7.91, 71.22, 32.35 Participant 3: 14.97, 44.49, 14.78 Participant 4: 13.43, −7.34, −72.22	Students differed in terms of intellectual and physical functioning and received individual support and programming, among which physical or occupational therapy, as needed
Pan (2010)	Average: 57.26	Motor function: 73.17 Social functioning: 37.3	*Aquatic skills (HAAR):* Stage I: 5.26 Stage II: 75.61 Stage III: 33.33 Stage IV: 187.52 Stage V: 64.60 *Social behaviour (SSBS-2):* Peer relations: 27.52 Self-management/compliance: 26.4 Academic behaviour: 44.74 Social competence total: 39.21 Hostile/irritable: 43.44 Antisocial/aggressive: 31.42 Defiant/disruptive: 42.17 Antisocial behaviour total: 43.46	In addition, some of the participants regularly received after-school occupational, physical, group, and speech therapy
Pan (2011)	Physical fitness: 16.19 Aquatic skills: 52.59 Average: 32.74	Motor function: 32.74	*Physical fitness:* BMI: 1.62 Body fat: 3.21 Curl-ups (30s): 32.29 Curl-ups (60s): 23.4 Sit and reach: 13.9 16-m PACER: 22.74 *Aquatic skills (HAAR):* Stage I: 6.06 Stage II: 14.76 Stage III: 66.68 Stage IV: 42.10 Stage V: 133.35	No ongoing medication but current therapy was maintained
Pitetti et al. (2007)	Average: 6.84	Motor function: 6.84	*Fitness* BMI: 8.48 Weight: 5.20	Participants took medication, which is detailed
Rogers et al. (2010)	Skills were mastered at an average rate of 92.59	Motor function: 92.59	Motor skills Child 1: 88.89 Child 2: 88.89 Child 3: 100	Two of the three participants received speech therapy

Table 2 (*Continued*)

Study	% overall improvement	% improvement by domain	% improvement by variable	Concomitant medication and/or treatment
Rosenthal-Malek and Mitchell (1997)	Average: 27.4	Motor function: 42.55 Rest category: 12.26	*Self-stimulatory behaviour:* 45.86 improvement following exercise during academic condition 39.23 improvement following exercise during workshop condition *Academic responding:* 13.51 improvement following exercise precondition. *Tasks completed:* 11 improvement following exercise precondition.	No information
Todd and Reid (2006)	Average: 150.8	Motor function: 150.81	*Physical activity* Child 1: 150 Child 2: 100 Child 3: 202.44	No information
Yilmaz et al. (2004)	Average: 62.4	Motor function: 65.51 Communication: 50	*Autistic behaviour:* Swinging: 28.57 Spinning: 100 Echolalia: 50 Reaction: 50 *Fitness:* Average score: 83.47	No information

Table 3
Improvement rates (%) as a function of Type of Intervention and ASD problem area.

	Motor skills	Social skills	Other	Average
Individual	48.35	71.43	12.26	48.57
Group	35.98	26.37	24.74	31.54
Average	40.38	39.51	21.62	

Note: Scores reflect average improvement and do not necessarily add up to 100%.

individuals with ASD took part in the interventions. Gender and age were reported for 101 participants: 22 were female and 79 male and the average age was 13.6 years (range: 4–41.3 years). The gender distribution was consistent with the male/female ratio generally reported for the ASD population (Newschaffer et al., 2007).

2.5. Exercise interventions

The physical exercises reported in the 16 studies under review were swimming ($n = 5$), jogging ($n = 6$), horseback riding ($n = 2$), cycling and weight training ($n = 1$), walking ($n = 1$) and other physical activities ($n = 1$). The effects of the activities were mostly gauged in the three core symptom areas of ASD, i.e., motor, social and communication skills, but in some cases also effects on attention, academic engagement and physical condition were assessed. In Table 1 the studies included in the analysis are summarized.

2.6. Data analysis

In order to compare the studies on the dimensions described, improvement scores of all the variables that were assessed were expressed in percentages reflecting the observed behavioural change between two measurements. This mostly concerned the difference between a baseline value obtained prior to the exercise or intervention and a value obtained shortly after exercise/programme completion. Two studies failed to report a baseline measurement (Elliot et al., 1994; Rosenthal-Malek & Mitchell, 1997). For these two studies we took the differences with the control groups as input for our analysis. Percentages larger than zero were taken to reflect behavioural improvement.

For each study, an overall improvement score was calculated. For studies that reported a compound dependent variable consisting of various submeasures, the total average score of the submeasures was entered into the analysis. For studies reporting on more than one participant with ASD, the mean percentage score across the participants was calculated.

The dependent measure was statistically evaluated by means of Mann–Whitney U tests to assess the differential effects of (i) individual versus group interventions, (ii) individual versus group interventions for each of the two ASD problem areas (motor and social skills) and (iii) individual versus group interventions for the two most frequently reported types of exercise interventions.

3. Results

Pooled across all studies and independent factors our meta-analysis revealed an overall improvement score of 37.5%. Clearly, physical exercise yielded positive behavioural changes.

Table 2 shows the scores per study evaluated. Type of Intervention proved to be a significant factor ($U = 442.0$, $z = -2.885$, $p = .004$, medium effect size $r = -0.32$). Overall, the participants with ASD profited more from individual interventions ($M = 48.57\%$) than from group interventions ($M = 31.54\%$).

Table 3 provides the mean improvement scores per ASD problem area and Type of Intervention (individual versus group). If studies reported dependent variables that did not fit into one of the primary ASD problem areas, their data were assigned to a rest category ("other"). As to motor skills, individual programmes yielded larger positive effects than group activities ($U = 145.5$, $z = -2.051$, $p = .040$, medium effect size $r = -0.31$). The social interaction domain also showed a statistically significant difference ($U = 0.00$, $z = -3.046$, $p < .000$, medium effect size $r = -0.62$). Surprisingly, here the individual interventions also generated a larger positive effect ($M = 71.43\%$) than the group interventions ($M = 26.37\%$). An analysis of the rest category was not possible because the limited amount of data did not warrant a reliable statistical evaluation.

Jogging and swimming were the two most frequently applied therapeutic exercise activities. A separate analysis for swimming showed a significant difference between individual and group interventions ($U = 30$, $z = -2.642$, $p = .008$), with the former producing higher improvement rates ($M = 30.5\%$) than the latter ($M = 17.4\%$). A separate analysis for jogging showed no such difference for Type of Intervention ($p > .05$).

4. Discussion

The present meta-analysis served to provide insight into the impact of physical exercise on people with Autism Spectrum Disorders. Sixteen studies describing exercise-based interventions reported positive and promising effects in two of the three core symptom domains: motor and social deficits. Results pertaining to communication skills were insufficient to

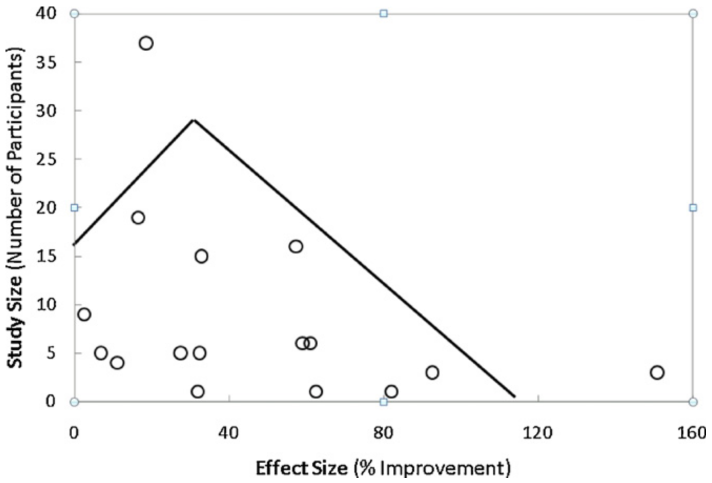

Fig. 1. Funnel plot showing the study size, as reflected by the number of ASD participants in the 16 studies evaluated, as a function of the effect size, a expressed as percentage of improvement.

allow systematic evaluation. As expected, our analysis of the motor variables yielded larger positive effects for interventions that were offered on an individual basis. Surprisingly, although to a lesser degree, this also held for social skills, thus disproving our hypothesis that group-based exercise programmes would be more effective in this symptom domain. This counterintuitive result may be attributed to differences in concepts. The definition of ''group intervention'' in the literature is broader than the definition of ''individual intervention''. A group is usually defined as ''two or more people who interact with, and exert mutual influence on, each other'' (Weinberg & Gould, 2006). Unfortunately, we could not find any publications with a naturalistic group-based sport intervention like soccer (Table 2). In the eight studies we categorized as group interventions it was not always clear whether there actually were any meaningful social interactions between the participant with ASD and (one or more of) his/her other team or staff members. It is likely that in the individual interventions therapist–client interactions were more frequent and more intensive. Future research needs to describe these interactions more clearly to allow differential effects of the two treatment approaches on social deficits to be determined.

Another important consideration is that our search did not generate any study reporting non-significant effects. This publication bias (Sterne, Gavaghan, & Egger, 2000) either implies that sport or exercise always has a significant effect on people with ASD or, alternatively and probably more likely, that studies with non-significant effects were not published. Given the general tendency in behavioural science to ignore null effects (Harcum, 1990), the findings of our meta-analysis may be positively biased, particularly in view of the modest size of the experimental groups (Table 2). Then again, the funnel plot in Fig. 1 depicting the number of participants in the selected studies against the effect sizes that were reported in terms of our relative improvement rates (in percentages) is reasonably symmetric.

Even after the data of the two outlier studies – the two data points falling outside the triangle displayed in Fig. 1 – had been eliminated, our meta-analysis still showed a 35% improvement rate in the ASD samples as a result of physical exercise. Future experimental studies should test the reliability of our findings, preferably by using a mixed between- and within-subject design.

A further point of discussion is the large heterogeneity of the experimental samples in the studies that met our inclusion criteria. Irrespective of the fact that all the children and adults involved in the studies were reported as having been diagnosed with ASD and most of them in accordance with DSM criteria, the disorders within the spectrum are, as explained in the introduction, quite heterogenic in nature (Vandereijcken et al., 2008). Consequently, of the 133 individuals tested some had severe autism while others were described as high functioning persons with autism or as having Asperger's syndrome. Hence our findings cannot be generalised to the ASD population as such and the various results should be interpreted relative to the severity of impairment.

A final drawback of our meta-analysis is the variation in concomitant medication and therapies (see right-hand column in Table 2). Most studies briefly mention that medication and/or therapy were continued as usual throughout the study period, including the times the effects of physical exercise were assessed. Some mention that medication or treatment was temporarily discontinued and several studies provide no information. Overall, it is suggested that confounding effects of medication and therapy on the reported impact of the exercise-based interventions were marginal to absent.

In sum, despite the heterogeneity of the experimental groups and other potentially confounding factors (e.g. small subject groups and continuation of treatment as usual), the 16 behavioural studies we analysed showed robust benefits of physical exercise on the patients' motor and social functioning. Further experimental research is needed to determine the extent to which these improvements depend on ASD severity (cf. Pan, 2011) as well as longitudinal studies assessing their robustness over time.

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