Cognitive Processing
https://doi.org/10.1007/s10339-020-00992-6

REVIEW

Autism, autistic traits and creativity: a systematic review and meta-analysis

Paola Pennisi[1] · Laura Giallongo[2] · Giusy Milintenda[2] · Michela Cannarozzo[1]

Received: 16 December 2019 / Accepted: 5 September 2020

Abstract

Psychometric, historiometric and psychiatric studies are controversial on a hypothetical link between psychopathology and creativity. In this study, we will try to contribute to this debate by analysing the case of autism. Is there a relationship between autism and creativity? If so, can we find the same relationship in a watered-down form in subjects with autistic traits? In order to answer these questions, we carried out a systematic literature review of the studies on this topic published in the last 10 years. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. We also conducted a meta-analysis of data. We found that in the clinical population there are fewer creative performances than in control groups; nonetheless, it is possible to delineate a medium creative profile of subjects with autism. The average creative profile of people with autism shows that they are inhibited in fluency and flexibility, but that they display a high level of detail and a particularly high level of originality in works either generated during tests or created in private time. In particular, the level of detail reached in the latter condition seems to be higher in the autistic population than in the control groups. Better linguistic skills appear to be linked to better creative performances. Linguistic tests, if compared with visual and performative tests, seem to favour the expression of originality in subjects with autism. Although our data on autistic traits are compatible with the hypothesis that a high level of autistic traits is a watered-down replica of the cognitive profile of subjects with autism, we have no sufficient data to support this hypothesis.

Keywords Autism · Psychopathology · Creativity · Language · Originality · Autistic traits · Meta-analysis · Systematic review

Introduction

The idea of an intimate connection between creativity and psychopathology has been potent since Aristotle's time. Van Gogh, Alda Merini, Guillaume Apollinaire, Guy de Maupassant, Friedrich Nietzsche and many more: the list of creators who suffered from some form of psychopathology is incredibly long (cfr. i.e. Bogousslavsky and Boller 2005).

Until now, no one has definitely demonstrated neither the truthfulness, nor the falsity of this link. In fact, whilst psychologists are frequently inclined to consider creativity an expression of mental health, the historiometric, psychiatric and psychometric research prevalently promotes the idea that psychopathological symptoms are recurrent in creators (Simonton 2005). Correlations between psychopathological traits and creative production have been found in cases of mental disorders (Simeonova et al. 2005; Power et al. 2015); on the other hand, degenerative disorders seem to cause inhibition of creativity, at least in

Handling editor: Thomas Lachmann (University of Kaiserslautern).

Reviewers: Réka Vágvölgyi (University of Kaiserslautern), SaskiaJaarsveld (University of Kaiserslautern), Andreas A Ioannides(AAISCS, Nikosia), Joana Carmo (University of Lisbon).

✉ Pennisi Paola
ppennisi@unime.it

[1] Department of Adult and Childhood, Human Pathology "Gaetano Barresi"; Hospital G. Martino, University of Messina, Via Consolare Valeria snc, 98125 Messina, Italy

[2] Department of Cognitive Science, Education and Cultural Studies, University of Messina, Via Concezione 6/8, IT, 98121 Messina, Italy

Published online: 15 October 2020

non-artist patients (Palmiero et al. 2012).This work is an attempt to clarify the relationship between psychopathology and creativity by focusing the attention on creativity in subjects with autism spectrum disorders.

Autism spectrum disorders (ASD) are neurodevelopmental disorders characterized by persistent deficits in social communication and interaction and restricted and repetitive patterns of behaviour, interests or activities (APA 2017). The typical cognitive profile of these patients is also characterized by the lack of spontaneous symbolic play (Low et al. 2009), cognitive inflexibility and very poor dreamlike activity (Daoust et al. 2008). In spite of the typical characteristics of the autistic phenotype, today we number a lot of eminent creators in the spectrum: Temple Grandin, Daniel Tammet, Nadia (Pennisi 2016a, b, c; Selfe 2011), Stephen Wiltshire, Gregory Blackstock are a few examples, but here too the list could go on and on. The cognitive profile of subjects with autism, in fact, also shows characteristics that seem to predispose these patients to a very original style of thought, i.e. anomalies in visual thought (Grandin 2013; Low et al. 2009); anomalies in imagination (Crespi et al. 2016; Hamilton et al. 2009); anomalies in the use of spatial reference frames (Giovannini et al. 2006); and preference for non-social rather than for social stimuli (Pierce et al. 2011).

In relation to this problem, until now the scientific literature has adopted three different approaches: the first is to consider autism as lacking creativity (cfr. i.e. Cassella 2011). In this case, the extraordinary skills showed by autistic savants are explained as special characteristics (i.e. a superior memory) that are different from and unrelated to creativity. In the second approach, the two phenomena are addressed as unrelated (cfr. i.e. Cardinal 2009). This perspective is more common in researchers working in the artistic field than in researchers working in the psychopathological field and highlights that the appeal of art is linked not to a dramatic diagnosis or sensational biographies, but to the experience that it triggers in spectators. The third approach explains the extraordinary performances of autistic creators by attributing them to some feature of the autistic cognitive phenotype (cfr. i.e. Baron-Cohen et al. 2009; Happé and Vital 2009). However, in this last case we would need to explain why not all subjects with autism are eminent creators.

There is, in fact, another question related to this topic: the case of the savant syndrome. The savant syndrome is a condition in which patients with serious mental disabilities (autism, other forms of developmental disabilities, mental retardation or other impairments of the central nervous system) show some special, extraordinary skill; some 'islands of genius' (Treffert 2009). There is not a total overlapping between autism and savant syndrome, but 30% of subjects with autism have savant syndrome (Howlin et al. 2009) and 50% of subjects with savant syndrome are within the autism spectrum (Treffert 2009; Rimland 1978).

The partial overlapping between savant syndrome and autism has exerted a strong attraction in popular accounts of ASD. As noted by Happé and Frith (2009), the result of this fascination was the beginning series of studies that looked for autistic traits in famous geniuses such as Newton or Einstein. According to the authors, although it seems undeniable that, at certain levels, there is a correlation between autism and creative aptitudes, the diffusion of a simplistic way of attributing autistic traits is likely to be misrepresentative of both autism and talent.

To make a contribution to this debate, we analysed the scientific literature on the topic and tried to answer the following questions: is there a relationship between autism and creativity? If so, are subjects with autism more or less creative than subjects without autism? Can we explain the extraordinary creativity of some subjects with autism by relating the pathology to their cognitive profile? If so, why are not all subjects with autism eminent creators? Can we hypothesize a typical creative profile of the autistic creator? Do subjects with autistic traits who never received the diagnosis and subjects with autism share similar creative skills?

Theoretical background: creativity in autism

Baron-Cohen et al. (2009) argued that talent in autism is linked to three characteristics widespread in the autistic spectrum: sensory hypersensitivity, attention to details, and the tendency to marked systematization of the world. The main idea is that sensory hypersensitivity of subjects with ASD enables them to develop great attention to details. They exploit this ability to understand the world by applying a systematizing principle through rules such as "if *x*, then *y*".

The advantage of this approach is that, like the weak central coherence theory (Frith 1989), it views autism as a different cognitive style and not as a series of cognitive deficits. This theory can explain part of the creative phenomena in the spectrum, and specifically the ones related to the role of learning and experience in the enhancement of creativity; however, it does not take into consideration that the "islands of genius" (Treffert 2009) are not usually the result of training, but innate talents. According to Treffert (2009), islands of genius are linked to the brain's ability to rewire its connectivity in certain circumstances, by recruiting the capacity of other brain areas.

At a neurobiological level, the substantial inconsistency of the studies conducted on single areas or on single networks has greatly favoured the idea that autism is associated with brain connectivity anomalies and that these are then a possible consequence of the functional anomalies of brain activation (Müller and Fishman 2018). In this perspective, anomalies in cerebral connectivity can explain

the high percentage of savants in the autistic population as well as other phenomena. That is, there is strong evidence of increased prevalence of synaesthesia in subjects with ASD (Neufeld et al. 2013). Increased connectivity has been found both in subjects with ASD and in synaesthetes (Courchesne et al. 2005; Hänggi et al. 2011), and it has recently been hypothesized that synaesthesia is caused by a cross-activation of adjacent brain areas (Hubbard and Ramachandran 2005; Ramachandran 2012). Moreover, sensorial hypo- and hyper-acuity and social anomalies can also be linked to anomalies in connectivity because both sensory pathways and social-emotional pathways (respectively the parieto-occipital tracts and the temporal tracts) show impaired connectivity in subjects with ASD (Chang et al. 2014).

Anomalies in cerebral connectivity can be linked to an original way of perceiving the world. But creativity is not only originality nor is it only the result of innate and never trained talents. On the contrary, many other aspects of creativity depend on practice and general thinking style. Like Simon Baron-Cohen et al. (2009), we also believe that in part the tendency to hyper-systematize the world can contribute to making some creative performances of subjects with autism original and effective. Where our idea differs from that of the one of these authors is in the cause–effect relationship between style of thought and characteristics of autism. Rather, in our opinion, the tendency to hyper-systematize is not the cause of excessive attention to details; on the contrary, we think that sensory and perceptual anomalies are in turn the cause of a different and therefore original style of thought.

For example, if a child with autism is not subject to the magnetic attraction of the other's gaze like a TD child, his attention may be drawn to something else, something that TD subjects would typically define as a detail in the background, such as a light switch next to the linguistic partner. In fact, it is possible that the vacuum left by the lack of interest in social cognition pushes the individual to be more interested in the rest. A greater interest in the non-social world could then better reward a cognitive style of the "if *x*, then *y*" type than the social world does because non-social phenomena are more obedient to this explanatory model. In this way, in a virtuous circle, the child with autism will become more skilled in inferences of physical causation than in the social world ones (Pennisi 2016a, b, c) and the acquisition of language, if it should occur, will present anomalies related to the use of a different style of thought (Pennisi 2016c, 2020). The reduced interest in social stimuli could be the basis of the tendency to prefer an "if *x*, then *y*" style, but it does not make this style of thought automatic or mandatory for the subject: the great mathematical mind of Daniel Tammet, for example, is able to think of numbers both in mathematical terms and in synaesthetic terms (Tammet 2006).

In support of our perspective, it should also be noted that sensory problems are a defining characteristic of the spectrum (American Psychiatric Association and American Psychiatric Association 2017), but the tendency to hyper-systematize is not. Our idea is that the latter is not a primary characteristic of subjects with autism, but that in some subjects it may develop as a consequence of their propensity to neglect the social aspects of life.

This style allows them to effect creative performances, which, on the one hand, are original because they are elaborated originating from different sensory systems; on the other hand, they can be very analytical, making the creator able to predict what will happen by applying the system of rules he has gradually developed: perhaps anomalies in the connectivity in Temple Grandin's brain can explain her incredible and innate ability to visualize her projects in the mind. In this case, a happy combination between some forms of sensory acuity and development of the tendency to hyper-systematize could be the basis of the famous scientist's great creativity.

This theoretical approach could also help explain phenomena such as the regression of talent in some savants ("A creative profile for subjects withautism" section), innate talents in the clinical population and the heterogeneous diffusion of creativity in the clinical population.

The concept of cognitive style has another positive consequence: if the tendency to systematize is a widespread trait also in the TD population (Baron-Cohen 2003), it may be useful to investigate the relationship between characteristics of the autistic style of thought and levels and characteristics of creativity in the TD population. If in fact the tendency to systematize is associated with characteristics of creative performances which are very similar in both the clinical and the TD population, then the role of sensory anomalies, reduced attention to social stimuli and innate talent islands in subjects with autism should be considered all in all unimportant for creative characterization. On the contrary if, despite the same tendency to systematize, the two populations were to show very different characteristics of creativity, then the role of sensory anomalies and the tendency to socialize should be taken into greater consideration when studying creativity.

A working definition for *creativity*

From a psychological point of view, the two main characteristics of creativity academics seem to agree on are *originality* and *efficacy* (Runco and Jaeger 2012). The three main categories into which the concept of creativity is usually fragmented are: divergent thinking (Runco 2008), insight and artistic creativity (Dietrich and Kanso 2010).

Divergent thinking is usually opposed to convergent thinking and is the cognitive strategy used to solve problems in unconventional ways. It requires the capacity to suppress

the cognitive biases generated from the logic imposed by the culture we live in or from our inner stream of consciousness. With the term *insight* we generally mean a *Eureka* experience, which is characterized by a strong emotional response relating to the satisfaction of having overcome an impasse in a clever way, but without a clear consciousness of the reason that led to such a solution. The concepts of *insight* and *divergent thinking* are often associated. The Remote Associate Test Mednick (1968), for example, which is widely used to assess divergent thinking, has also been used in many studies on insight.

In some ways, even artistic creation could be included in this working definition. In fact, according to Merlin Donald, art "involves the deliberate construction of representations that affect how people (including the artist) view the world" (Donald 1991: 4). This means that every artist necessarily has to solve the problem of constructing a representation of the subject that has an effect on the audience. In order to be considered an authentic act of creation, such a representation needs to be the expression of the author's uniqueness and originality. As such, artistic creativity can be included in the following definition of *creativity*: "the ability to find original and effective solutions to a specific problem". This will be our working definition for *creativity*.

Methods

The aim of this paper is to review and discuss current evidence regarding the topic. We adopted a quantitative perspective and referred to an average value in samples taken from the normal population (rather than among eminent creators as historiometric studies usually do). We synthesized the results through a systematic review and also conducted five meta-analyses. A systematic literature research was performed using Scopus, Science Direct, PubMed and ISI Web. The search terms were "autism" and "creativity" in all fields (title, abstract, keywords, full text and bibliography); the time range was 01.01.2009–18.04.2019.

Through database searching, we identified 289 studies. These were reduced to 178 after duplicates were removed. Included and excluded studies were collected following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al. 2009). See flow diagram (Fig. 1).There is no review protocol for this work.

Screening and eligibility criteria

The first author initially screened all titles and abstracts. The aim was to exclude studies that were not centred on autism or on autistic traits, or that did not deal with creativity. The first screening led to the exclusion of 75 results.

After the screening, we assessed 103 results for eligibility. The following is the full list of inclusion and exclusion criteria for assessing eligibility.

Inclusion criteria

a. The study had to be experimental. We have excluded studies that had no original experimental perspective, such as surveys, and research that was not associated with any scientific experiment.
b. The study had to be focused entirely or partially on creativity in subjects with autism or subjects with autistic traits. In the latter case, we only took into account data on creativity. We included only studies that made a clear distinction between creativity and all the other measurements taken.
c. The study had to include at least one group of participants with a diagnosis of ASD or a group of participants in which the autism quotient or the autistic traits were evaluated through quantitative tools.
d. The study that included a group of participants with a diagnosis of ASD had to include at least one control group as well.

Exclusion criteria

e. Case studies.
f. Studies focused on how to enhance creativity in subjects with autism, on how to test creativity in general or on how to develop tools to test creativity.

Final sample

In this phase, two researchers from the team individually evaluated whether to exclude or include every single work. The works on which there was a disagreement (n = 3) were then discussed collectively, and their inclusion or exclusion was finally decided unanimously. Before discussion, the % of inter-judges agreement was 87.06% (Cohen's $k = 0.56$). During the eligibility assessment, we excluded 39 results because they did not fulfil the inclusion criteria (a = 26; b = 8; c = 5) and 41 results because they fell within our exclusion criteria (e = 8; f = 33). The eligibility assessment led to exclusion of a total of 79 results.

Statistical analysis

In harmony with meta-analytic recommendations, we (a) collected data from each single study; (b) calculated standardized mean difference effect sizes for each comparison (Cohen's *d*) (Cohen 1988); (c) determined the overall effect sizes for each comparison with a random effect model; (d) identified potential moderator variables; (e) measured heterogeneity through I^2 (Higgins and Green 2006; Rosenthal

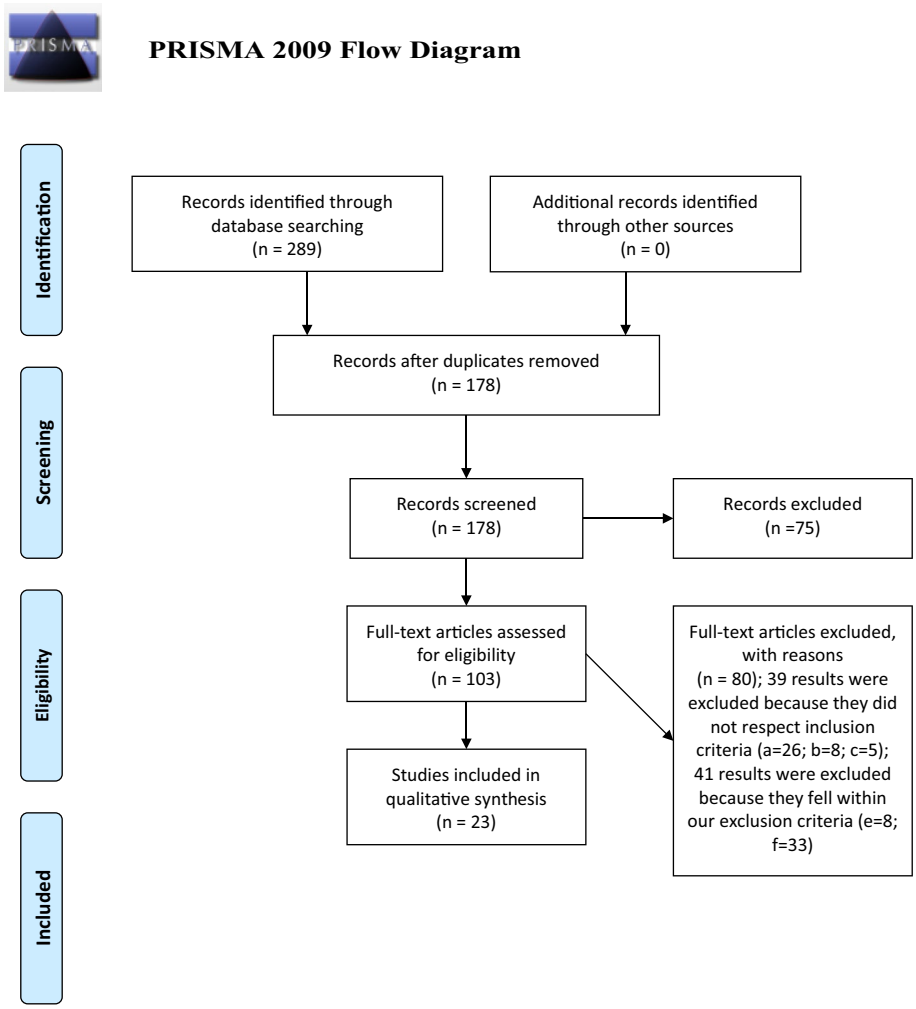

Fig. 1 Prisma flow diagram for the systematic review

1995); and (f) used the classic fail-safe N (Rosenthal 1979) and the Duval and Tweedie's trim and fill procedure (Duval and Tweedie 2000) in order to evaluate publication bias. The null hypotheses were: (H1) subjects without ASD have higher scores in creative tests than subjects with ASD; (H2) subjects without ASD have higher scores than subjects with ASD in fluency when tested for creative skills; (H3) subjects without ASD have higher scores than subjects with ASD in flexibility when tested for creative skills; (H4) subjects without ASD have higher scores than subjects with ASD in elaboration when tested for creative skills; (H5) subjects without ASD have higher scores than subjects with ASD in originality when tested for creative skills. To evaluate the significance of the results, we used Cohen's (1988) parameters: where $d = 0.00$ is a null effect; $d = 0.20$ is a small effect; $d = 0.50$ is a medium effect; $d = 0.80$ is a big effect. In this way, if d has a positive value, the control group has higher scores than the clinical group, if d has a negative value the clinical group has higher scores than the control group.

To interpret heterogeneity, we used Higgins and Green's (2006) parameters. So we considered $I^2 = 0$–24 as null; $I^2 = 25$–49 as low; $I^2 = 50$–74 as moderate; and $I^2 = 75$–100 as high.

For testing of the first hypothesis, we have a sample of 12 studies ($k = 12$); in this case, the trim and fill analysis is more reliable than the fail-safe N. On the contrary, all the other hypotheses have $k < 10$; in this case, the fail-safe N is probably more reliable than the trim and fill analysis which is based on a funnel plot.

Results

Our final sample for the systematic review consisted of 23 results. Thirteen of them were focused on the relationship between autism and creativity (Table 1); 10 of them were focused on the relationship between autistic traits and creativity (Table 2). Studies on the relationship between autistic traits and creativity are still too few and heterogeneous, so no meta-analysis was conducted on them. Moreover, we excluded from the meta-analysis the study by Kyaga et al. (2013) because of the excessive heterogeneity of its structure

Table 1 Comparison of studies focused on the relationship between autism and creativity

Study	ASD group[a]	Control group[a]	Matched on	Test of interest for H1	Main Results for H1
Constable et al. (2017)	23 subjects with ASD Age: 40.35 (12.3) VIQ: 110 (19.3) PIQ: 109 (19.5) FIQ: 111 (19.2) AQ: 35.6 (6.2)	24 TD subjects Age: 38.71 (12.4) VIQ: 117 (13.7) PIQ: 111 (16.4) FIQ: 115 (16.4) AQ: 14.38 (6.4)	Age Verbal IQ Performance IQ Full-scale intelligence quotient (all from WAIS III or IV; Wechsler 2000, 2008)	PERFORMATIVE TEST Vygotsky Block Test (Vygotsky 1987): divergent thinking task	The group with ASD scored lower than the TD group Unlike the control groups, in the group with ASD the VIQ correlated with the number of principles and the number of subgroups generated by the participant
Dichter et al. (2009)	39 subjects with ASD Age: 9.72 (2.66) PIQ: 101.69 (17.5) SCQ: 16.49 (3.77) CCC-2: 63.73 (25.05) RBS-R: 25.87 (15.93)	39 TD subjects Age: 10.57 (3.35) PIQ: 111.67 SCQ: 3.54 (0.35) CCC-2: 8 (8.11) RBS-R: 1.74 (2.86)	Age	LINGUISTIC TEST AFT (Lezak 1995) The UOT (Turner 1999) LIPS-R (Roid and Miller 1997). Measure of non-verbal intelligence, here PIQ. SCQ (Rutter et al. 2003) CCC-2 (Bishop 1998) RBR-R (Bodfish et al. 1999)	The ASD groups reported significantly fewer correct responses and more incorrect responses than the TD group for the AFT Groups did not differ in the number of repetitions of previous responses and in the total number of responses. In the UOT, the ASD group reported fewer total and correct responses. Groups did not differ in the number of incorrect responses, in the number of repetitions and in the number of unusual responses The only significant correlation between autistic condition and generativity (ability to produce multiple unique and appropriate responses) was with communication impairments (CCC-2) No correlation was found between repetitive behaviours and generativity
Hobson et al. (2009)	16 subjects with ASD Age: 6.5 (2.91) VMA: 5.25 (1.91)	16 subjects with LD or DD Age: 10.33 (1.5) VMA: 5 (1.16)	Age Receptive VMA (BPVS, Dunn et al. 1982)	PERFORMATIVE TEST Rating of individual play sessions with toys and one of the experimenters for child's "flexible use of objects" and "propensity to introduce new and creative ideas to enrich the play" by experts	No significant differences between the two groups in flexibility, or in creativity

Table 1 (continued)

Study	ASD group[a]	Control group[a]	Matched on	Test of interest for H1	Main Results for H1
Hobson et al. 2012	27 subjects with Autism Age: 5.83 (1.5) VMA: 2.66 (1.08) PlayMA: 2.75 (1.08) 14 subjects with ASD (they met some but not all the criteria of autism and were diagnosed with atypical autism, AS or pervasive developmental disorder) Age: 5.33 (1.41) VMA: 2.66 (0.91) PlayMA: 3.16 (1)	16 subjects with DD Age: 5.91 (1.5) VMA: 2.91 (0.66) PlayMA: 3.25 (0.91)	Age VMA (PLS-III UK Ed.; Zimmerman et al. 1997)	PERFORMATIVE TEST ADOS-G (Lord et al. 1999) Rating of individual play sessions by experts for child's creativity (propensity to introduce new and creative ideas)	Autism group scored lower than ASD and the control group in creativity ASD group scored lower than the control group in creativity The degree of children's communication/social interaction impairment (subscale of ADOS) was associated with poorer scores in creativity VMA correlated with creativity across all groups
Jolley et al. (2013)	15 subjects with ASD Age range: 6.83–18.16 VMA range: 3.16–11.66	15 subjects with moderate LD 15 TD subjects 15 TD subjects	Age Receptive VMA (BPVS) Age Receptive VMA (BPVS)	VISUAL TEST Rating of quality of expression on a 7-point scale of two drawings for each participant by two artists	TD group matched for age scored significantly higher than each participant in the other three groups No other group differences were found
Kasirer and Mashal (2014)	17 subjects with ASD Age: 21.06 (3.44) AQ: 29.17 (2.03) TONI-3: 38.8 (4.13) Naming: 46.47 (1.73) Vocabulary: 48.18 (6.46)	17 TD subjects Age: 22.71 (2.02) TONI-3: 46.71 (1.82) Naming: 46.71 (1.82) Vocabulary: 55.82 (3.34)	Age Non-verbal intelligence, TONI-3 (Brown et al. 1997) Naming (Hebrew naming test; Kavé 2005a, b) Phonemic fluency (Kavé 2005b) Semantic fluency (Kavé 2005b)	LINGUISTIC TEST Vocabulary sub-test from WAIS (Wechsler 1997) Metaphor comprehension Metaphor and simile generation Tests for Executive Functions	The ASD group produced more metaphors than TD group The ASD group showed a greater percentage of original responses than TD group Generation of metaphors was predicted by the TONI-3

Table 1 (continued)

Study	ASD group[a]	Control group[a]	Matched on	Test of interest for H1	Main Results for H1
Kasirer and Mashal (2016)	34 subjects with ASD Age: 12.59 (1.62) TONI-3: 33.35 (6.85) Naming: 44.56 (2.57) Vocabulary: 45.62 (7.05) TMT A: -0.94 (1.82) TMT B: -0.23 (1.48) AMGT: 10.06 (6.61) Phonemic fluency: 21.59 (7.97) Semantic fluency: 38.50 (8.75)	39 TD subjects Age: 12.26 (1.58) TONI-3: 31.85 (6.57) Naming: 44.26 (2.66) Vocabulary: 47.15 (5.84) TMT A: -0.2 (1.19) TMT B: 0.49 (0.86) AMGT: 17.03 (2.9) Phonemic fluency: 27.72 (9.56) Semantic fluency: 43.18 (11.57)	Age TONI-3 Hebrew naming test Vocabulary sub-test from WIS-C (Wechsler 2003) Phonemic fluency (Kavé 2005a, b) Semantic fluency (Kavé 2005a, b)	LINGUISTIC TEST Metaphor comprehension Conventional metaphor generation Novel metaphor generation	The ASD group scored lower than TD group in the conventional metaphor generation test The ASD group performed better than TD group in the novel metaphor generation test The ASD scored higher in the novel metaphor than in the conventional metaphor generation test, unlike the members of the TD group, who did not show any difference Phonemic fluency was predictive of performances in novel metaphor generation in both groups, but had greater influence in the ASD group
Kirchner et al. (2016)	32 subjects with ASD Age: 30.9 (8.4) Education (years): 14 (2.9) SWL: 2.9 (1.2)	32 TD subjects Age: 30.9 (8.4) Education (years): 13.8 (2.9) SWL: 4.5 (1.4)	Age; gender; education; employment status	LINGUISTIC TEST Values in Action Inventory of Strengths (Peterson and Seligman 2004; German version Ruch et al. 2010)	Creativity was significantly more often a signature strength in ASD than in TD
Kuo et al. (2014)	14 subjects with AS Age: 17.93 (2.06) VIQ: 115.14 (17.32) PIQ: 102.36 (15.58) FIQ: 110.07 (15.79)	24 TD mathematically and scientifically talented (MST) students with a high IQ Age: 18.63 (1.58) 17 TD MST students with an average IQ Age: 19.82 (1.74) 29 TD subjects Age: 20.07 (1.51)	Age WAIS 3rd edition, Chinese version, Chen and Chen 2002)	LINGUISTIC TEST The Me Scale II (Chang 2011)	The group with AS showed significantly stronger creative over-excitability than the TD group (here over-excitability is intended as "higher than average responsiveness to stimuli"; Dabrowski 2015)

Table 1 (continued)

Study	ASD group[a]	Control group[a]	Matched on	Test of interest for H1	Main Results for H1
Kyaga et al. (2013)	42.024 subjects with ASD	65.589 subjects with schizophrenia 14,905 subjects with schizoaffective disorder 68,915 subjects with bipolar disorder 438,372 subjects with unipolar depression 212,758 subjects with anxiety disorder 340,784 subjects who suffered from alcohol abuse 136,490 subjects who suffered for drug abuse 48,024 subjects with ADHD 17,276 subjects with anorexia nervosa 73,766 who committed suicide	Born in Sweden since 1932 and registered as living in Sweden after 1960; being registered in the National Patient Register (National Board of Health and Welfare), which provided discharge diagnoses for all inpatient treatment episodes in Sweden 1973–2009, or being registered as suicide in The Cause of Death Register; having answered to the self-report questionnaires of national censuses in 1960, 1970, 1975, 1980, 1985 or 1990 or being registered in the national register LISA (Statistics Sweden)	PROFESSION AND LIFE ANALYSIS Statistical analysis to investigate if psychiatric disorders are over-represented in creative professions Statistical analysis to investigate if psychiatric disorders are over-represented in authoring something Statistical analysis to investigate if there is a correlation between being first-degree relative of a patient with psychiatric disorders and practising creative professions or being an author	Autism was not over-represented in creative professions Practising a creative profession had significantly reduced the likelihood of being diagnosed with autism Autism was not over-represented among authors
Liu et al. (2011)	16 subjects with AS Age: 16.06 Age range: 10.5–11.7 VIQ: 117.8 (14.2) TONI-3: 99.3 (15.4)	42 TD subjects Age: 10.4 Age range: 10.2–11.9 VIQ: 118.4 (11.5) TONI-3: 98.7 (13.1)	Age PPVT-R (Dunn and Dunn 1981)	VISUAL TEST From a creativity assessment package (Williams 1980): An exercise in divergent thinking (12 incomplete figures to be drawn). Scores for: fluency; openness; flexibility; originality; elaboration; titles An exercise in divergent feeling (self-rating creativity questionnaire). Scores for: curiosity, imagination, complexity, risk-taking. TONI-3	The AS group scored significantly higher than TD group in originality and in elaboration and significantly lower in openness and in flexibility TONI-3 and PPVT-R correlated with divergent thinking in the AS group more than in TD group TONI-3 and PPVT-R correlated with divergent feeling more in TD group than in AS group

Table 1 (continued)

Study	ASD group[a]	Control group[a]	Matched on	Test of interest for H1	Main Results for H1
Pring et al. (2012)	9 savants with ASD Age: 34.55 (5.13) VIQ: 83.66 (17.49) PIQ: 84 (18.50) 9 non-talented adults with ASD Age: 32.22 (6.59) VIQ: 78.78 (14.79) PIQ: 82.33 (16.59)	9 non-talented adults with mild/moderate LD Age: 33.56 (5.49) VIQ: 95.11 (17.86) PIQ: 83.55 (19.19)	Age Gender VIQ (PPVT) PIQ (RSPM, Raven 1960; or CPM, Raven 1956)	VISUAL TEST The incomplete and repeated figure tasks of the TTCT; (Torrance 1974). Four factors were taken into account: fluency, originality, elaboration, flexibility Figural synthesis task (with eight shapes taken from Finke and Slayton 1988)	Talented art students performed better than all groups in all tasks except for originality in the figural synthesis task, in which they performed similarly to savants Savants performed better than ASD and MLD in elaboration at the TTCT Savants and ASD scored similarly in originality and performed better than the group with MLD in the figural synthesis task (however, the difference between ASD and art students is significant, despite the equivalence between the performances of savants and those of talented art students)
		9 TD talented art students Age: 17.44 (0.72) VIQ: 114.67 (12.99) PIQ: 114 (9)	Gender (7:2 m:f)		
Weiss et al. (2014)	12 children with AS Age: 7.7 (1.4) IQ: 115 (8.9) 12 adolescents with AS Age: 12.2 (1.4) IQ: 111.4 (11.3)	12 TD children Age: 7.6 (1.3) IQ: 116.5 (9.7) 12 TD adolescents Age: 12.3 (1.5) IQ: 11.09 (12)	Age Non-verbal intelligence (CFT1 Version for children, Weiβ and Osterland 1997; CFT 20-R Version for adolescents, Weiβ and Weiβ 2006)	VISUAL TEST Der 5-Punkte Test (Regard et al. 1982) TTCT	In all groups, children scored lower than adolescents AS groups scored lower than TD groups in fluency and flexibility No other significances were reported

In Table 1, we present data from studies in our sample that answer Q1 through a quantitative measure. The works reviewed here often take into account more aspects than those included in the table, but we considered only those of interest for Q1 in order to make our table easier to read. That is, Hobson et al. (2012), in the rating of individual play sessions, assessed not only *creativity*, but also *self-awareness in creating new meanings*, *investment in symbolic meanings* and *fun*; however, we referred exclusively to the term *creativity* because it is the parameter we are interested in

We excluded the study of Best et al. (2015) from this table because their sample of subjects with ASD had no confirmed diagnosis, but simply declared having received the diagnosis in an online survey. At the end of Table 2, there is the full list of abbreviations used in Tables 1 and 2

[a]In these columns, the first value is always the mean, the second in brackets is always the standard deviation. Age (chronological, verbal, mental) is always expressed in years. When original papers expressed age by using both age and months (i.e. "12;4" to indicate 12 that subjects were 12 years and 4 months old, we converted the data into years and reported "12.3")

Table 2 Comparison of studies focused on the relationship between autistic traits and creativity

Study	Composition of the group with autistic traits[a]	Test for assessing autistic traits	Description of the test	Main results for our questions
Best et al. (2015)	312 subjects with subclinical autistic traits Age: 35.63 (13.79)	SATQ (Kanne et al. 2011)	Participants were asked to provide as many uses as they could think of either a brick or a paper clip (1 min per object) (variation of the alternate uses test by Guilford et al. 1978) Participants were asked to provide as many interpretations as they could of some images (1 min per figure) (variation on the Wallach and Kogan tests of creativity by Wallach and Kogan 1965)	The level of autistic traits was: Negatively correlated with Wallach and Kogan figure fluency Correlated with unusualness of answers in multivariable linear regression analyses
Campbell and Wang (2012)	1077 high-functioning young adults, students at University	Presence of parents with ASD	Online survey on personal intellectual interests for pursuing studies and presence of neuropsychiatric disorders in the family	Students interested in pursuing technical majors (science, mathematics or engineering) were more likely to report a sibling with ASD Students interested in studying humanities were more likely to report a family member with bipolar disorder, major depressive disorder or substance abuse problems
Claridge and MacDonald (2009)	77 students Age: 20.7 Age range: 17.9–26.6	O-LIFE (Mason et al. 1995) AQ (Baron-Cohen et al. 2001)	Divergent thinking tasks selected from Wallach and Kogan (1965) Similarities task: participants were given a pair of words and were asked to list as many similarities between the words as they could in 2 min Pattern meanings task: participants were shown a pattern and asked to generate as many explanations as possible trying to be as creative as possible Convergent thinking tasks: Missionaries and Cannibals and Tower of Hanoi from Garnham and Oakhill 1994	Weak correlations between autistic traits and convergent thinking were found

Table 2 (continued)

Study	Composition of the group with autistic traits[a]	Test for assessing autistic traits	Description of the test	Main results for our questions
Dostal et al. (2015)	1112 university students from Palacký University n Olomouc (Czech Republic) (836w–276 m) Age: 22.77 (2.12) Age range: 19–30	EQ and SQ (Baron-Cohen et al. 2001)	The K-DOCS (Kaufman 2012). It contains a list of 50 creative behaviours. Respondents had to rate their creativity for each behaviour on a 5-point scale. Five scales of creativity are assessed: Self/Everyday; Scholarly; Performance; Mechanical/Science; Artistic. CAQ (Carson et al. 2005)	The SQ correlated significantly with: K-DOCS Mechanical/Scientific and Scholarly scales CAQ Invention and Scientific Discovery and Architecture scales The EQ correlated significantly with: K-DOCS Self/Everyday; Performance and Scholarly scales
Drake and Winner (2009)	15 children gifted in realistic drawing Age: 9.16 (1.41) VIQ: 120.7 (11.2) nonVIQ: 133.9 (12.9) 13 children moderately gifted in realistic drawing Age: 8.66 (1.25) VIQ: 112.8 (10.3) nonVIQ:116.9 (13.5) 15 children with age-typical skills in drawing Age: 8.91 (1.66) VIQ: 113.6 (13.7) Non VIQ: 110.9 (13.9)	Realism in drawing rated by independent judges	KBIT-II (Kaufman and Kaufman 2004) to test VIQ e nonVIQ Block design task (first in un-segmented form and then in segmented form) to assess the ability to break designs down their parts. A design must be copied using blocks, each one of which is a component of the design Visual memory test (Caron et al. 2006) Analysis of drawing strategy	The gifted group had a non-verbal and verbal IQ higher than both the other groups In the block design task, the gifted subjects with autism: Did not benefit from the facilitation effect of the segmented condition experienced by other groups Did not suffer a drop in of performance when the perceptual cohesiveness increased, unlike the other groups In the visual memory test, gifted subjects performed better than the other two groups
Jankowska et al. (2019)	526 students Age: 21.48 (2.78) Age range: 18–40 140 of them were classified as having a BAP (AQ)	AQ (Baron-Cohen et al. 2001)	TCP (Karwowski and Jankowska 2016); a self-report measure of creative abilities, openness and independence TCIA (Jankowska and Karwowski 2015); drawings and descriptions of imagery created are assessed for vividness, originality and transformativeness TCT-DP (Urban and Jellen 1996); a performance-based test in which participants have to complete a drawing starting with six elements placed asymmetrically on the test sheet. It includes fourteen different criteria	Slight differences in creativity were observed between participants classified as having a BAP and other participants: Participants with a BAP had performed slightly better than others at performance-based creativity tests Participants with a BAP revealed lower scores in self-reported creative abilities Both results were weak but were significant

Table 2 (continued)

Study	Composition of the group with autistic traits[a]	Test for assessing autistic traits	Description of the test	Main results for our questions
Kasirer and Mashal (2018)	54 students Age: 12.59 (2.05) TONI-3: 32.09 (6.80) AMGT: 14.41 (6.30) Fonemic fluency: 29.22 (9.28) Semantic fluency: 41.35 (10,.11)	Language-based executive function tests such as: AMGT (Mashal and Kasirer 2011) Phonemic fluency (Kavé 2005b) Semantic fluency (Kavé 2005b)	Novel metaphor generation	No correlations between executive functions and metaphor generation were found
Knudsen et al. (2019)	35 Big-C visual artists Age: 43 (7) Education (level): 18.4 (1.7) IQ: 111.4 (10.6) 41 Big-C visual scientists Age: 45 (8) IQ: 114.1 (10.1) 31 smart comparison group Age: 42 (9) Education (level): 18.9 (1.3) IQ: 113 (10.3)	SRSA-II (Constantino 2012)	TTCT (Torrance 1967) BWAS (Barron & Welsh 1952). Participants had to decide whether they "liked" or "disliked" drawings with various levels of complexity WAT (Eysenck 1994). Participants generated single word responses across three conditions: free response; common response; idiosyncratic response. Responses were scored for production frequency RAT (Mednick 1962). Participants tried to generate a missing connector word for three prompt words. This is a measure of divergent thinking	Big-C visual artists scored higher than other groups on SRSA-II No significant correlations between tests on creativity and autistic traits were found
Takeuchi et al. (2014)	895 healthy subjects Age: 20.82 (1.84)	Japanese version of SQ and EQ (Baron-Cohen 2003; Baron-Cohen and Wheelwright 2004)	S-A creativity test (Society_For_Creative_Minds 1969) to assess Divergent thinking. Three verbal tasks: 5 min to generate unique ways of using objects 5 min to imagine desirable functions of ordinary objects 5 min to imagine consequences of "unimaginable things"	Higher divergent thinking performances correlate with both higher SQ and higher EQ

Table 2 (continued)

Study	Composition of the group with autistic traits[a]	Test for assessing autistic traits	Description of the test	Main results for our questions
Zabelina et al. (2014)	100 participants Age: 20.55 (2.51) AQ: 17.85 (6.45)	AQ (Baron-Cohen et al. 2001)	ATTA (Goff and Torrance 2002) to assess divergent thinking: 3 min to name problems that may arise from being able to walk on air or fly without being in an airplane (written responses) 3 min to use incomplete figures to make pictures (two figural responses) CAQ (Carson et al. 2005) to assess real-world creative behaviour in ten creative domains (visual art, music, dance, architectural design, creative writing, humour, inventions, scientific discovery, theatre and film, culinary arts). For example, in the music domain "I have no training or recognized talent in this area" is 0; "My compositions have been critiqued in a national publication" is 7	Divergent thinking was not significantly predicted by AQ

ADHD attention deficit hyperactivity disorder, *ADOS* Autism Diagnostic Observation Schedule, *AFT* Animal Fluency Task, *AMGT* Ambiguous Word Meaning Test, *AQ* Autistic quotient, *AS* Asperger Syndrome, *ASD* Autism Spectrum Disorders, *ATTA* Abbreviated Torrance Test for Adults, *BAP* Broad Autism Phenotype, *BPVS* British Picture Vocabulary Scale, *BWAS* Barron-Welsh Art Scale, *CAQ* Creative achievement questionnaire, *CCC-2* Children Communication Checklist-2, *CFIT* Culture Fair Intelligence Test, *CPM* Coloured Progressive Matrices, *DD* developmental delay, *EQ* empathy quotient, *FIQ* full intelligence quotient, *IQ* intelligence quotient, *K-DCS* Kaufman Domains of Creativity Scale, *KBIT-II* Kaufman Brief Intelligence Test-II, *LIPS-R* Leiter International Performance Scale-Revised, *LL* learning difficulties, *PIQ* performance intelligence quotient, *PlayMA* play mental age, *PLS-III UK Ed.* Preschool Language Scale-III United Kingdom Edition, *PPVT* Peabody Picture Vocabulary Test-Revised, *RAT* Remote Associate Test, *RBS-R* Repetitive Behaviours Scale-Revised (Bodfish et al. 1999), *RSPM* Raven's Standard Progressive Matrices, *SAQ* Subthreshold Autism Questionnaire, *SCQ* Social Communication Questionnaire, *SQ* systemizing quotient, *SRSA-II* Social Responsiveness Scale for Adults—Second edition, *SWL* Satisfaction with life, *TCIA* Test of Creative Imagery Abilities, *TCQ* Types of Creativity Questionnaire, *TCT-DP* Test of Creative Thinking-Drawing Production, *TD* typically developed, *TMT A* Trail making test part A, *TMT B* Trail making test part B, *TONI-3* Test of Non-verbal Intelligence-3, *TTCT* Torrance Test of Creative Thinking, *UOT* use of object task, *VIQ* verbal intelligence quotient, *VMA* verbal mental age, *WAIS* Wechsler Adult Intelligence Scale, *WAT* Word Association Test, *WIS-C* Wechsler Intelligence Scale for Children

[a]In these columns, the first value is always the mean, the second in brackets is always the standard deviation. Age (chronological, verbal, mental) is always expressed in years. When original papers expressed age by using both age and months (i.e. "12;4" to indicate 12 that subjects were 12 years and 4 months old, we converted the data into years and reported "12.3")

in comparison with all the others. Thus, the final sample for the meta-analysis consisted of 12 results (cfr. table 3 for terminological equivalences).

Our research questions were on the difference between subjects with autism spectrum disorders and the rest of the population. We considered Asperger Syndrome (AS) as being part of the more general group of ASD. Typically developed (TD) subjects are those who have never received any psychiatric diagnosis. In our sample, subjects with autism were usually compared with TD subjects, but sometimes they were compared with subjects with learning difficulties (LD) or developmental delay (DD). For the meta-analysis, we unified these three populations in a more general control group (CG). It was impossible to carry out analysis of subgroups because their small size did not allow for adequate generalizability of the data. The results are presented in Table 4.

Before starting the analysis, we paid great attention to terminological equivalences between our outcomes and some concepts used by the authors in our sample. For example, some authors in the sample consider originality and creativity analogous concepts. We disagree with this idea. As we indicated in Sect. 1.2, creativity for us has two essential characteristics: originality and efficacy. Efficacy is fully part of our definition of creativity. That is, using a chewing gum to glue a glass is certainly an original solution, but, according to our definition, it is not a creative act because it is not effective.

Let's now consider the paper written by Kasirer and Mashal (2014). In this work, researchers gave participants a questionnaire with some concepts and asked them "to create and write down a new expression, which is more comprehensible within your peer group than outside it". Whereas Kasirer and Mashal considered the generation of unconventional metaphors made by the participants as an index of creativity, we considered it as an index of originality. In our opinion, it is plausible that an original metaphor is less comprehensible in the peer group than outside it. In this case, we believe that what should have been viewed as an indicator of creativity was a composite score of novel and conventional metaphor generation. In some cases, in fact, it is likely that using a more conventional expression is an effective solution to problems such as the one posed by this experimental setting.

Is creativity under- or over-represented in the autistic population in comparison with the non-autistic population?

In the final sample of our systematic review, 13 studies answered the above-mentioned ("Introduction" section) questions through quantitative comparisons of groups. We collected the main comparisons in Table 1.

On the basis of the results of individual studies, we classified them into three groups: studies that found that subjects with autism scored lower than CG; studies that found that subjects with autism scored higher than CG and finally studies that did not find any advantage or disadvantage in the autistic condition in creative performances. For this analysis, we considered the study of Jolley et al. (2013) twice. In this study, the ASD group is compared with other three CG. In the first group, there are 15 TD subjects matched for chronological age [ASD vs. TD]; in the second, there are 15 subjects with DD matched with the ASD group for verbal mental age (VMA) [ASD vs. DD]; in the third comparison group, there are 15 TD subjects matched with the ASD group for VMA [ASD vs. TDxVMA].

The first group is made up of six elements: Constable et al. (2017); Dichter et al. (2009); Hobson et al. (2012); Jolley et al. (2013) [ASD vs. TD]; Pring et al. (2012); Weiss et al. (2014). These studies found that subjects with autism showed lower test scores in creative tasks than control subjects. The second group is made up of four elements: Kasirer and Mashal (2014, 2016); Kitchner et al. (2016); Kuo et al. (2014). These studies, in contrast, showed that subjects with autism performed better than control subjects in creative tasks. The third group is made up of four elements: Kyaga et al. (2013); Hobson et al. (2009); Jolley et al. (2013) [ASD vs. TD] and [ASD vs. TDxVMA]; Liu et al. (2011). Among them, Kyaga et al. (2013) found that subjects with autism were not over-represented in creative professions compared to the rest of both clinical and non-clinical population. Hobson et al. (2009), Liu et al. (2011) and Jolley et al. (2013) [ASD vs. DD] and [ASD vs. TDxVMA] did not find any advantage or disadvantage in the autistic condition compared to the control groups. Therefore, the studies in the third group indicate that there are no differences between the autistic population and the non-autistic one; in the light of this, it seems that the narrative review supports the idea that creativity is quantitatively under-represented in the autistic population in comparison with the non-autistic one.

The meta-analysis confirms this hypothesis, with a small effect ($d = 0.24$). Cfr. the forest plot in Fig. 2. The heterogeneity is moderate ($I^2 = 64.16$). Both the numerical moderators considered (the chronological age of participants and the publication year of the study) were not significant. The fail-safe N suggests the possibility of publication bias (13, when $5k + 10 = 70$), whereas the more precise trim and fill analysis excluded the presence of publication bias for this analysis. Cfr. the funnel plot in Fig. 3.

In order to explain the moderate heterogeneity, we set up two sessions of data analysis. In the first one, we attempted to understand if the type of test performed was a predictor of one conclusion rather than of another ("Task-based analysis" section). In the second session of data analysis, we focused on the concept of creative profile instead. In order

Table 3 Terminological equivalences between our terms and the corresponding term in the studies in our sample

Our term	Definition	Index for the meta- analysis	Paper
Creativity = the ability to find original and effective solutions to a specific problem	Divergent thinking	Composite score of the Vygotsky Block Test	Constable et al. (2017)
	Generativity	Correct responses at the Animal Fluency Task and at the Use of Object Tasks	Dichter et al. (2009)
	Propensity to introduce new and creative ideas to enrich the play	Scores in *creativity* during play sessions	Hobson et al. (2009) and Hobson et al. (2012)
	Quality of expressive drawings	Rating of independent judges	Jolley et al. (2013)
	Conventional and novel metaphor generation	Mean responses	Kasirer and Mashal (2014, 2016)
	Creativity	Self-evaluation of strengths	Kirchner et al. (2016)
	Creative over-excitabilities	Self-evaluation of talent	Kuo et al. (2014)
	Divergent thinking	Composite mean score of the divergent thinking task	Liu et al. (2011)
	Creativity	Composite mean score of the Torrance Test of Creative Thinking	Pring et al. (2012) and Weiss et al. (2014)
Fluency = quantity of responses produced for each request	Quantity of given responses	Quantity of given responses at the Animal Fluency Task and at the Use of Object Task	Dichter et al. (2009)
	Quantity of generated metaphors and similes	Mean responses	Kaiser and Mashal (2014)
	Quantity of metaphor generation	Effect of group on metaphor generation	Kaiser and Mashal (2016)
	Quantity of drawing with an easily recognizable figure	Score in *fluency* of the divergent thinking task	Liu et al. (2011)
	The total number of responses completed by each participant	Score in *fluency*	Pring et al. (2012)
	Total number of correctly solved items of the 5-point test	Score in *fluency*	Weiss et al. 2014
	Quantity of correct responses for each task (fluency/quantity)		Best et al. (2015)
	A composite score for fluency and originality was created by calculating a z-score for the number of original responses on each task and adding these to give a total of originality **Fluency = Total number of responses for each task.**		Claridge and McDonald (2009)
	They calculated all the four characteristics of TCTT separately, but did not find significant differences when they elaborated the four dimensions in a unique composite score		Takehuchi et al. (2014)

Table 3 (continued)

Our term	Definition	Index for the meta- analysis	Paper
Flexibility = ability to produce semantically different ideas	Number of principles and subgroups generated (divergent thinking)	Scores at the divergent thinking task of the Vygotsky Block Test	Constable et al. (2017)
	Ability to use objects in more than one way	Score in *potential for flexible use of objects* during play sessions	Hobson et al. (2009)
	Higher scores were associated with quantity of different characteristics for each drawing	Scores in *flexibility* at the divergent thinking task	Liu et al. (2011)
	Ability to produce ideas that are semantically different	Scores in *flexibility* at the TTCT	Pring et al. (2012)
	Flexibility	Scores in *flexibility* at the TTCT	Weiss et al. (2014)
	A complex modification of an original figure by mental imagery (transformativeness; for in-depth understanding of the meaning of this term cfr. Jankowska and Karwowski 2015)		Jankowska et al. (2019)
	They calculated all the four characteristics of TCTT separately, but did not find significant differences when they elaborated the four dimensions in a unique composite score		Takehuchi et al. (2014)
Elaboration = level of detail reached by each answer	Investment in symbolic meaning: higher when the child, during pretend play, invested greatly in caring about a new meaning given to an object	Score in *Investment in symbolic meaning* during play sessions	Hobson et al. (2009) and Hobson et al. (2012)
	The more symmetrical the drawings, the lower the score in elaboration	Scores in *elaboration* at the divergent thinking task	Liu et al. (2011)
	The amount of detail added to a drawn response, ability to carry out and develop an idea	Scores in *elaboration* at the TTCT	Pring et al. (2012)
	Clarity, complexity and elaboration of the imagery generated (vividness; defined in Jankowska and Karwowski 2015)		Jankowska et al. (2019)
	They calculated all the four characteristics of TCTT separately, but did not find significant differences when they elaborated the four dimensions in a unique composite score		Takehuchi et al. (2014)

Table 3 (continued)

Our term	Definition	Index for the meta- analysis	Paper
Originality = statistical rarity of answer	Unusual responses in the use of object task	Quantity of unusual responses at the Animal Fluency Task and at the Use of Object Task	Dichter et al. (2009)
	Creativity	Quantity of novel metaphor generation	Kaiser and Mashal (2014)
	Novel metaphor generation	Quantity of novel metaphor generation	Kaiser and Mashal (2016)
	The more unique the drawing, the higher the scores in originality	Scores in *originality* at the divergent thinking task	Liu et al. (2011)
	Rating of statistical rarity, based on a set of standardized norms	Scores in *originality* at the TTCT	Pring et al. (2012)
	Rarity and unevenness of the images	Scores in *originality* at the TTCT	Weiss et al. 2014
	Original responses were those given by less than 5% of respondents (unusualness)		Best et al. (2015)
	A composite score for fluency and originality was created by calculating a z-score for the number of original responses in each task and adding these together to give a total of originality		Claridge and McDonald (2009)
	Originality = one point for each response that was not given by any other participant		
	They calculated all the four characteristics of TCTT separately, but did not find significant differences when they elaborated the four dimensions in a unique composite score		Takehuchi et al. (2014)

In the first column, there is the definition of our outcomes. In the second column, there is the definition or the expression of the outcome in the paper of the sample. That is, in Dichter et al. (2009) the word "generativity" is used to refer to the quantity of correct responses. In the third column, there are the specific indexes used for the meta-analysis. In the fourth column, there are the papers taken into consideration case by case. The studies focused on the relationship between autism and creativity are in white; the studies focused on the relationship between autistic traits and creativity are in bold

Table 4 Results of the meta-analyses

Outcome	*k*	n_{CG}–n_{ASD}	ES (95%CI)	SE	Cohen's *d* interpretation	I^2	Fail-safe *N*	Trim and fill analysis
Creativity	12	367–289	0.24 [−0.03; 0.52]	0.14	Small effect	64.16	13 (pb = 70)	Trimmed studies = 0
Categorical moderator: linguistic tests	5	197–136	−0.01 [−0.38; 0.36]	0.19	Null effect	70.05		
Categorical moderator: visual tests	4	114–73	0.25 [−0.19; 0.70]	0.23	Small effect	53.13		
Categorical moderator: performative tests	3	56–80	0.72 [0.20; 1.24]	0.26	Medium effect	0		
Numerical moderator: chronological age	12	367–289	Y = −0.10 + 0.01X Sig. 0.719		Null hypothesis accepted			
Numerical moderator: publication year	12	367–289	Y = 338.01–0.06X Sig. 0.264		Null hypothesis accepted			
Fluency	6	179–148	0.38 [0.10; 0.66]	0.14	Small effect	33.35	11 (pb = 40)	Trimmed studies = 0
Moderator: linguistic tests	3	95–90	0.27 [−0.13; 0.67]	0.20	Small effect	52.24		
Moderator: visual tests	3	84–58	0.52 [0.08; 0.96]	0.22	Medium effect	17.82		
Numerical moderator: chronological age	8	211–205	Y = 0.26 + 0.01X Sig. 0.745		Null hypothesis accepted			
Numerical moderator: publication year	8	211–205	Y = 143.41 − 0.07X Sig. 0.247		Null hypothesis accepted			
Flexibility	5	124–97	0.97 [0.37; 1.57]	0.31	Big effect	76.63	49 (pb = 35)	Trimmed studies = 0
Moderator: visual tests	3	84–58	1.08 [0.20; 1.97]	0.45	Big effect	87.82		
Moderator: performative tests	2	79–40	0.80 [−0.29; 1.89]	0.56	Big effect	0		
Numerical moderator: chronological age	5	124–97	Y = 1.22 − 0.01X Sig. 0.698		Null hypothesis accepted			
Numerical moderator: publication year	5	124–97	Y = 78.88 − 0.04 Sig. 0.791		Null hypothesis accepted			
Elaboration	4	93–92	0.43 [−0.32; 1.19]	0.37	Small effect	81.99	3 (pb = 30)	Trimmed studies = 1 Estimate ES = 0.27
Moderator: visual tests	2	60–34	0.11 [−0.99; 1.21]	0.56	Null effect	91		
Moderator: performative tests	2	33–58	0.76 [−0.34; 1.87]	0.56	Medium effect	0		
Numerical moderator: chronological age	4	93–92	Y = 0.13 + 0.02X Sig. 0.686		Null hypothesis accepted			
Numerical moderator: publication year	4	93–92	Y = 49.72 − 0.02 Sig. 0.944		Null hypothesis accepted			
Originality	6	179–148	−0.27 [−0.76; 0.22]	0.24	Small effect	77.94	2 (pb = 40)	Trimmed studies = 0
Moderator: linguistic tests	3	95–90	−0.45 [−1.20; 0.30]	0.38	Medium effect	78.73		
Moderator: visual tests	3	84–58	−0.09 [−0.79; 0.62]	0.36	Null effect	83.47		
Numerical moderator: chronological age	5	140–109	Y = −1.15 + 0.05X Sig. 0.291		Null hypothesis accepted			
Numerical moderator: publication year	5	140–109	Y = 164.88 − 0.08 Sig. 0.694		Null hypothesis accepted			

to assess the performances of the participants, we organized the data considering the following characteristics: fluency; flexibility; originality; and elaboration ("Performance-based meta- analyses" section).

Task-based analysis

For the task-based analysis, we divided the studies on the basis of the type of task required from participants. We considered four categories of tests: (1) linguistic tests, when the participants were asked to produce a linguistic output (i.e. a spoken or written list of animals); (2) visual tests, when the participants were asked to produce a visual output (i.e. a drawing); (3) profession and life analysis (i.e. what the participants did for a living); and finally (4) performative tests, when the output was not a sign, but a practical performance (i.e. a play session). The groups we obtained are the following: linguistic tests (Dichter et al.

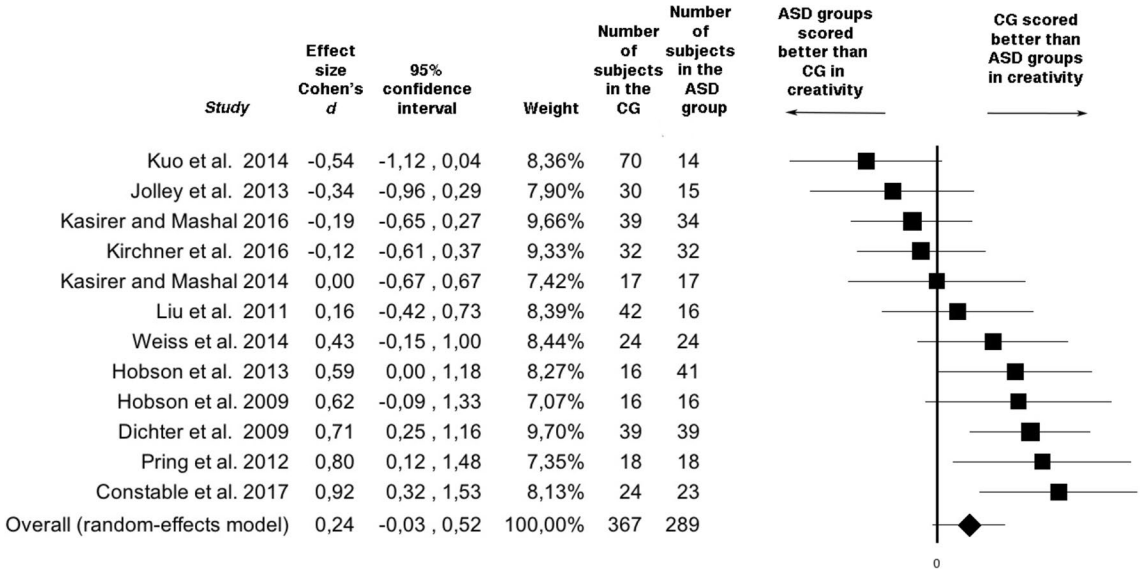

Fig. 2 Forest Plot of the "creativity" outcome. *Note*. The null hypothesis is rejected with a small effect

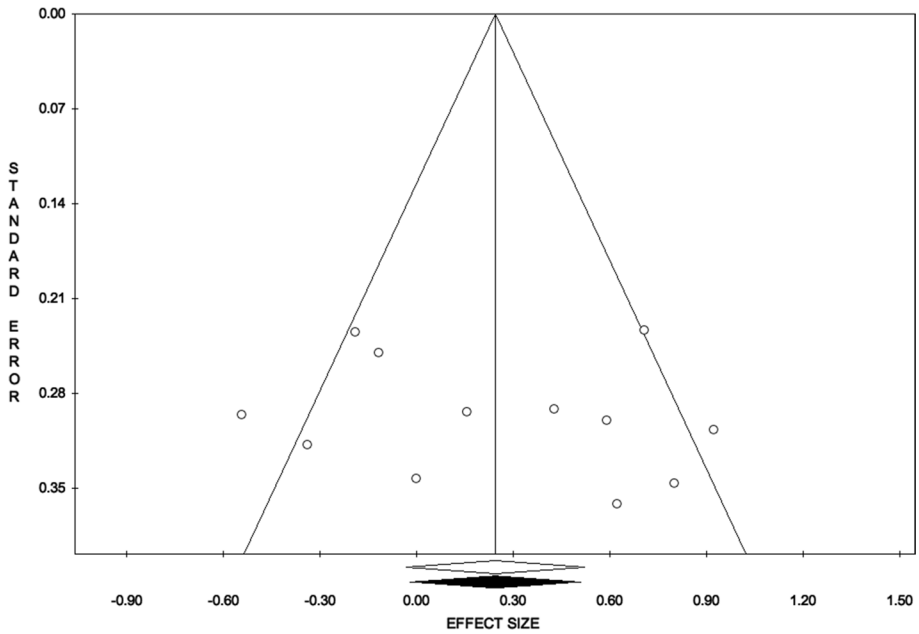

Fig. 3 Trim and fill analysis of the "creativity" outcome. *Note*. Funnel plot of the "creativity" *outcome*. There are no trimmed studies. The estimated effect size is the same of calculated effect size, so the analysis has no risk of publication bias

2009; Kasirer and Mashal 2014, 2016; Kirchner et al. 2016; Kuo et al. 2014 for autism and Best et al. 2015; Claridge and MacDonald 2009; Jankowska et al. 2019; Knudsen et al. 2019; Takeuchi et al. 2014; Zabelina et al. 2014 for autistic traits); visual tests (Jolley et al. 2013; Liu et al. 2011; Pring et al. 2012; Weiss et al. 2014 for autism; Drake and Winner 2009; Jankowska et al. 2019; Knudsen et al. 2019 for autistic traits); profession and life analysis (Kyaga et al. 2013 for autism; Campbell and Wang 2012; Knudsen et al. 2019; Zabelina et al. 2014 for autistic traits); performative tests (Constable et al. 2017; Hobson et al. 2009, 2012 for autism; Drake and Winner 2009; Knudsen et al. 2019; Zabelina et al. 2014 for autistic traits).

The systematic review showed that task-based analysis does not have a predictive value in relation to our questions for either autism or autistic traits. In fact, a simple comparison of the results of individual studies does not show clear evidence in favour of any kind of test. However, we inserted the kind of test as categorical moderator in the meta-analyses. In this way, we obtained data that, despite not being significant because of the very small sample of studies on

which they are based ($2 \leq k \geq 5$), could be helpful to formulate new explorative hypotheses for future studies. In fact, the result was null for linguistic tests ($d = -0.01$; $I^2 = 70.05$); small for visual tests ($d = 0.25$; $I^2 = 53.13$); and medium for performative tests ($d = 0.72$; $I^2 = 0$) (cfr. the forest plots in Fig. 4). Profession and life analysis was excluded because no study in the sample of the meta-analysis matched this category.

Performance-based meta- analyses

The most frequent evaluation of creativity in our sample allows for an organization of the concept in four characteristics, those assessed by the Torrance Test of Creative Thinking (TTCT; Torrance 1974): fluency, flexibility, elaboration and originality.

Fluency is the quantity of responses produced for each request and is the index of prolificacy. This index does not take into account the quality or the effectiveness of a subject's production.

Flexibility is the ability to produce semantically different ideas. An author, in fact, could be very prolific but repetitive. That is, let's consider the case of a researcher who asks two experimental subjects to write as many names of animals they are able to think of in a minute. Participant A writes: dog, Basset Hound; Bobtail; Jack Russell; Old English bulldog. Participant B writes: cat, dog and mouse. In this case, participant A is more fluent but less flexible; participant B is less fluent but more flexible.

Elaboration is the level of detail reached by each answer. It is the indicator of the creator's ability to represent a subject from a bottom-up perspective and of how much this bottom-up perspective enters the final output.

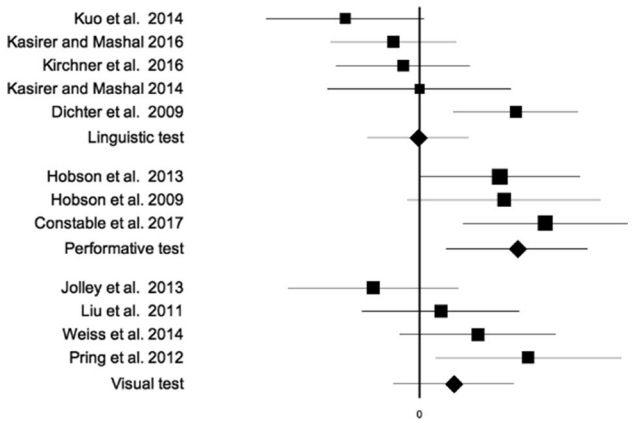

Fig. 4 Creativity. Task-based meta-analysis. *Note*. The analysis of kind of test as moderator indicates that creativity is not under-represented in the autistic population when assessed via linguistic test; on the contrary, it is under-represented when assessed via visual and performative test. Values below zero indicate better performances in the groups with ASD; values above zero indicate better performances in the control groups

Originality is the statistical rarity of answers. Let's take again the example of the researcher who asks participants to write as many names of animals they can think of in a minute. Participant A writes: cat, dog, mouse, fish. Participant B writes: dog with brown paws and white head; white Persian cat; grey mouse. Participant C writes: hedgehog, lizard, moray. In this case, participant C gives the smallest number of answers and appears therefore less fluent than the other two participants. Moreover, he does not provide details to characterize the animals on his list as participant B did, so his list is less elaborate than the latter's. However, the animals listed by participant C are not mentioned by the other participants, so his list is more original than the other two. In Table 3, we listed, paper by paper, how the authors of our sample represent these characteristics of creativity and which scores of the papers we took into account in the meta-analysis for each outcome.

According to Torrance (1974), the above-mentioned characteristics of creativity can be used to evaluate the general profile of creative skills in a subject. The higher the composite score, the higher the creative abilities of the subject. Each of the four characteristics contributes to the general score. This composite score does not fully account for the complexity of the concept of creativity, as admitted by Torrance himself; however, it is a fairly significant indicator, a sufficiently valid tool to try to give scientific uniformity to so many heterogeneous data without excessive simplification.

Can we hypothesize the prevalence of specific cognitive characteristics that are relevant in the act of creation and try to delineate a sort of creative profile for subjects with autism? Moreover, we also asked ourselves: are these hypothetical characteristics weakly replicated in a watered-down form in subjects with autistic traits?

Autism

Dichter et al. (2009), Pring et al. (2012) and Weiss et al. (2014) found that subjects with autism showed lower test scores than CG in fluency. Kasirer and Mashal (2014, 2016) and Liu et al. (2011) found no significant differences in fluency between groups. The meta-analysis showed that CG are significantly more fluent than subjects with autism ($d = 0.38$; $I^2 = 33.35$). Heterogeneity is low. The data were significant for all kinds of test (linguistic tests: $d = 0.27$; $I^2 = 52.24$; visual tests: $d = 0.52$; $I^2 = 0.02$; no papers of the sample tested fluency via performative tests) (cfr. the forest plots in Fig. 5). The fail-safe N showed the presence of publication bias (11, when $5k + 10 = 40$), whereas the fill and trim analysis excluded it (trimmed studies = 0).

Constable et al. (2017), Hobson et al. (2009), Liu et al. (2011), Pring et al. 2012 and Weiss et al. (2014) found that groups with ASD showed lower test scores than CG in flexibility. The meta-analysis indicated that CG had higher scores

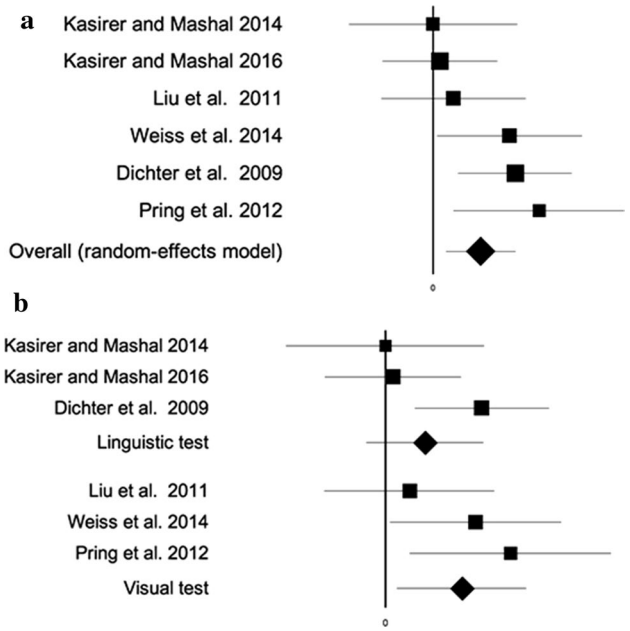

Fig. 5 Fluency. *Note*. **a** The meta-analysis indicates that CG are significantly more fluent than subjects with autism in creative test; **b** data were significant for linguistic and visual test. Values below zero indicate better performances in the groups with ASD; values above zero indicate better performances in the control groups

in flexibility than those with ASD ($d = 0.97$; $I^2 = 79.63$). The data were significant both for visual tests ($d = 1.08$; $I^2 = 87.82$) and for performative tests ($d = 0.80$; $I^2 = 0$). In our sample, there were no linguistic tests for flexibility (cfr. the forest plots in Fig. 6). The high level of heterogeneity in this case does not affect the assumption that CG are more flexible than people with ASD because the confidence interval (CI) is positive both at the lower (0.37) and at the upper limit (1.57) and is always above the line of significance ($d = 0.2$). Both the analyses on publication bias signalled the absence of bias (fail-safe N was 49, when $5k + 10 = 35$; no studies were trimmed in the fill and trim analysis).

Liu et al. (2011) found that subjects with ASD showed higher test scores than TD in elaboration. Pring et al. (2012) found that savants with autism produced more elaborative responses than the ASD and the MLD groups; but talented art students showed higher test scores than savants. Thus, the systematic review suggested that subjects with ASD are not affected in elaboration.

The meta-analysis also includes the scores of Hobson et al. (2009, 2012) in *investment in symbolic meaning*, which is the measure of how much children enrich an idea with details during a pretend play session. In these two studies, subjects with ASD had lower scores in elaboration than CG. For this reason, in contrast to the results of the systematic review, the meta-analysis indicates that subjects without autism produce more elaborate output in their creative tests; however, the effect is small ($d = 0.37$) (cfr. the forest plots in Fig. 7) and heterogeneity is high ($I^2 = 81.99$). The fail-safe N showed the presence of publication bias (3 when $5k + 10 = 30$). The fill and trim analysis trimmed 1 study, but the estimated effect (estimated $d = 0.27$) remained

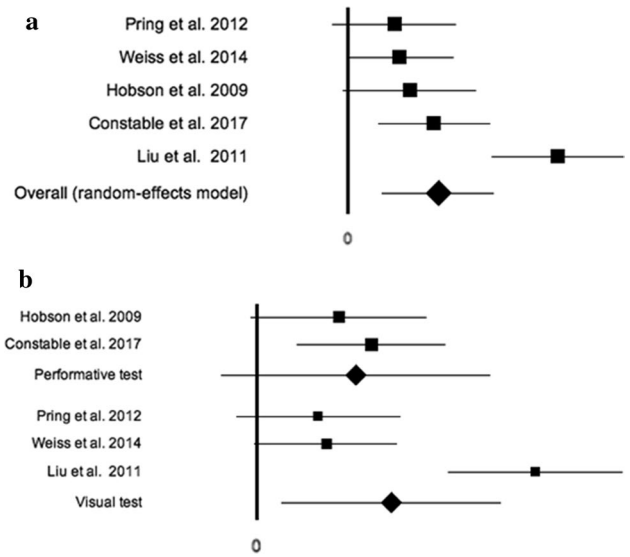

Fig. 6 Flexibility. *Note*. **a** The meta-analysis indicates that CG have higher scores in flexibility than subjects with autism in creative test; **b** data were significant for performative and visual test. Values below zero indicate better performances in the groups with ASD; values above zero indicate better performances in the control groups

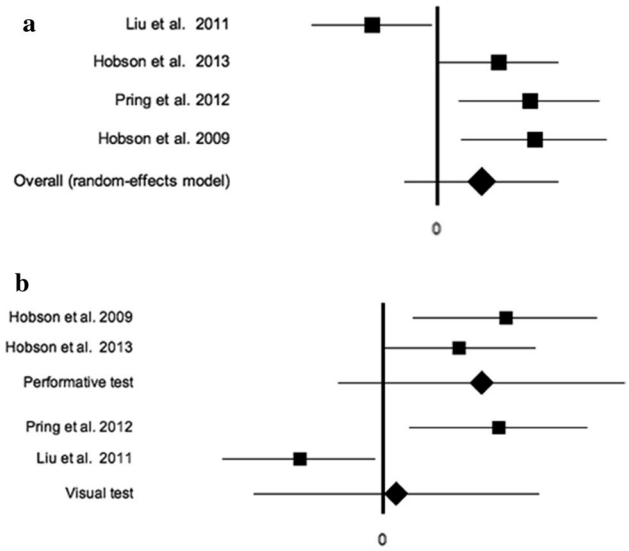

Fig. 7 Elaboration. *Note*. **a** The meta-analysis indicates that subjects with autism produce more elaborate output than CG in their creative tests; **b** data were significant for performative test and null for visual test. Values below zero indicate better performances in the groups with ASD; values above zero indicate better performances in the control groups

significant with a small effect. So, publication bias seems not to alter the significance of our analysis. The analysis of categorical moderator partially explains our high I^2. The high level of elaboration, in fact, has a null effect on visual tests ($d = 0.11$), even though heterogeneity remains high in this case ($I^2 = 91$). However, the analysis of performative tests is significant ($d = 0.76$) with no heterogeneity ($I^2 = 0$).

Finally, Kaiser and Mashal (2014, 2016) and Liu et al. (2011) found that subjects with autism show higher scores in originality than CG. Dichter et al. (2009) and Weiss et al. (2014) found no differences between the groups. Pring et al. (2012) found that CG scored higher than subjects with ASD in originality. The meta-analysis was significant ($d = -0.27$) (cfr. the forest plots in Fig. 8). The negative value means that people with ASD have higher scores in originality than CG groups. However, the level of heterogeneity is high ($I^2 = 77.94$). The CI is both positive and negative and above the level of significance in both cases. The categorical moderator partially explains this heterogeneity; the significance for linguistic tests, in fact, has a medium effect ($d = -0/45$), albeit with high heterogeneity ($I^2 = 78.73$). Data on visual tests are more controversial because, in this case, the analysis has a null effect ($d = -0.09$) and high heterogeneity ($I^2 = 83.47$). The fail-safe N indicated the presence of publication bias (2 when $5k + 10 = 40$), but the trim and fill analysis trimmed 0 studies.

The analysis of numerical moderators (chronological age of participants and publication year) was never significant.

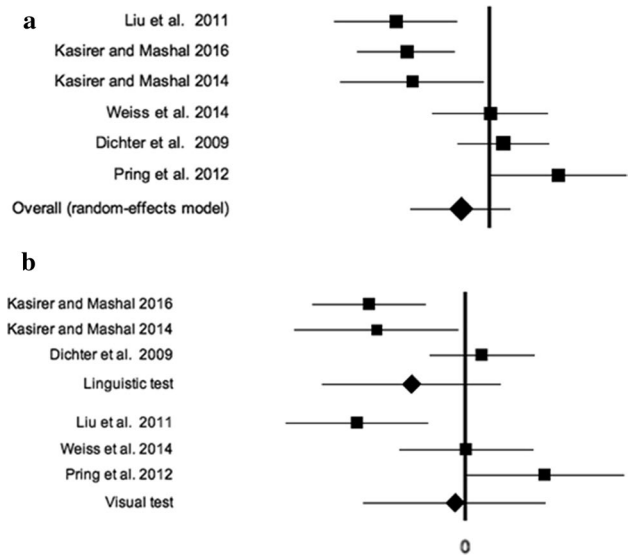

Fig. 8 Originality. *Note*. **a** The meta-analysis indicates that subjects with autism are more original in their creative test than CG; **b** data were significant for linguistic test and null for visual test. Values below zero indicate better performances in the groups with ASD; values above zero indicate better performances in the control groups

In both elaboration and originality, we have very high heterogeneity; moreover, we cannot explain this heterogeneity through categorical or numerical moderators; lastly, confidence intervals have very considerable values. For these reasons, and also considering the very low *k,* we concluded that systematic review is more suited than meta-analysis to synthesize the scientific literature on elaboration and originality.

Autistic traits

Studies on autistic traits are still inconclusive. Best et al. (2015) found that fluency is inversely correlated with the presence of autistic traits. This is in line with the creative profile we have delineated for subjects with ASD. Unfortunately, these data are not supported by Claridge and McDonald (2009), who found that a composite score for fluency and originality was not correlated with the autistic quotient AQ (Baron-Cohen et al. 2001). Moreover, Jankowska et al. (2019) found that subjects with a broad autism phenotype are slightly better than subjects without subclinical autistic traits in fluency in imagery (transformativeness). These data seem to contradict our creative profile of subjects with ASD, but the hypothesis of cortical under-connectivity between linguistic and imaginative processing in autism could explain this anomaly (Kana et al. 2006).

Best et al. (2015) found that originality is a significant positive predictor of the level of autistic traits. But also in this case, Claridge and McDonald's study (2009) does not confirm the data, since their composite score, which comprises originality and fluency, is not significantly correlated with AQ. Jankowska et al. (2019) also found no significant correlations between originality and autistic traits.

Jankowska et al. (2019) found no correlations between elaboration and autistic traits. Takehuchi et al. (2014) found that higher levels of a composite score of fluency, flexibility, originality and elaboration correlated both with systematizing quotient and with empathizing quotient.

To sum up, studies on autistic traits are still inconclusive.

The cognitive profile of creativity in subjects with autism

In "Performance-based meta- analyses" section, we showed that creativity seems to have varied characteristics in subjects with autism and that these characteristics are recognizable in the subjects' performances. Subjects with autism have a different cognitive profile to that of subjects without autism. The question that we will attempt to answer in this section is this: do the cognitive characteristics that affect creativity differ between subjects with and without autism? That is, does language have a different role in creative performance in subjects with and without autism?

In order to answer these questions, we analysed our sample by looking for correlations among: language ("Language

and creativity in autism" section), non-verbal intelligence ("Non-verbal intelligence and creativityin autism" section), executive functions ("Executive functions and creativity inautism" section), self-awareness ("Self-awareness and creativity inautism" section), age and other measurements ("Chronological age and othermeasurements" section).

Language and creativity in autism

We analysed the relationship between language and creativity in autism, in order to understand if linguistic abilities are predictive of better creative performances in subjects with autism.

Constable et al. (2017) found that subjects with ASD showed lower test scores than TD subjects in the divergent thinking task of the Vygotsky Block Test (Vygotsky 1987). Participants were also tested on verbal abilities, even though the Verbal IQ only correlated with both the quantity of categories and the quantity of subgroups in the group with ASD. Constable et al. (2017) interpreted these data by supposing that subjects with ASD relied on their verbal abilities more than the TD subjects while performing the task. Dichter et al. (2009) asked participants to name as many animals as possible within 1 min and to generate as many uses as they could for six different objects. In both cases, subjects with autism showed lower test scores than the control group. The generativity of subjects with ASD correlated with communication impairments but not with repetitive behaviours. Hobson et al. (2012) replicated an experimental setting (rating of play sessions) similar to the one performed in Hobson et al. (2009), but this time matching participants not for receptive verbal mental age by the use of BPVS, but for verbal mental age (VMA) using the Preschool Language Scale. They found that, across all groups, VMA correlated with creativity and that the degree of children's communication/social interaction impairment as assessed by the ADOS was associated with poorer scores in creativity. Jolley et al. (2013) found that a TD group matched for chronological age, a TD group matched for receptive VMA and a group with learning difficulties matched for receptive VMA performed better than the groups with ASD, but that there were no differences between the performance of the group with ASD and the two other groups matched for receptive verbal mental age.

In four of the five studies that found that subjects with autism showed higher test scores than control subjects in creative tasks (Kasirer and Mashal 2014, 2016; Kitchner et al. 2016; Kuo et al. 2014), the experimental task required the use of language. Moreover, in the first two (the only ones based on the assessment of the performance rather than of the self-esteem of the subjects), participants were matched for vocabulary skills through the Hebrew naming test (Kavé 2005a, b), the Kasirer and Mashal (2016) and the vocabulary sub-test from the Wechsler Intelligence Scale for Children (Wechsler 2003). Liu et al. (2011) found that TONI-3 and PPVT-R correlated with the divergent thinking task more in the AS group than in the TD group.

These data seem to indicate that language is a strong predictor for the development of general creativity in the autistic population. However, as we will discuss in "A creative profile for subjects withautism" section, this is probably not valid for elaboration too.

The heterogeneity of input data on language made it impossible to test the explorative hypothesis of a correlation between linguistic skills and scores in general creativity.

Non-verbal intelligence and creativity in autism

Constable et al. (2017) found a protective effect of higher PIQ against perseverative responding in ASD that is absent in TD subjects. Moreover, while in TD subjects PIQ never significantly correlated with performances in creative tasks, in subjects with ASD PIQ positively correlates with subgroups in the divergent thinking task.

Liu et al. (2011) found a positive correlation between TONI and divergent thinking in the AS group, but not in the TD one. Moreover, the authors found no significant correlation between PPVT-R and divergent thinking both in the AS and in the TD group.

Kasirer and Mashal (2014) found that high quotients of non-verbal intelligence (as assessed by TONI-3) were predictors of greater metaphor generation skills in subjects with autism. All these studies seem to indicate that high levels of non-verbal intelligence have a protective effect on creativity performances in subjects with autism. It was impossible to test these data in the meta-analysis through a moderator analysis because of the heterogeneity of the input data.

Executive functions and creativity in autism

Dichter et al. (2009) found that there were no correlations between repetitive behaviours (Repetitive Behaviour Scale-Revised, RBS-R, Bodfish et al. 1999) and creativity as assessed by Animal fluency task and Use of objects task. The correlation was absent both for total score of the RBS-R and for each subscale of the test. In the same direction, Hobson et al. (2009) found no correlation between flexible use of objects (which, in their task, was considered an index of executive functions) and the presence/absence of the diagnosis.

Kasirer and Mashal (2014) found that, whereas the comprehension of conventional metaphors in subjects with ASD is best predicted by vocabulary and picture naming, the comprehension of novel metaphors is best predicted by high score in the TMT Trail Making (a test to assess executive functions). Kasirer and Mashal (2016) also found a correlation between an index of executive functions (Kavé's

phonemic fluency test) and the generation of new metaphors. This correlation was absent in the TD group.

To sum up, these studies indicate that the role of executive functions in creative tasks is still unclear. It seems that executive functions have a role in the comprehension of others' creative behaviours, as well as in the comprehension of non-conventional metaphors. At the same time, Dichter et al. (2009) and Hobson et al. (2009) indicate that executive functions have no relationship with creative performances, whereas Kasirer and Mashal (2016), on the contrary, found a positive correlation. Further research is needed to understand the relationship between creativity and executive functions.

Hobson et al. (2009) found that during the execution of creative tasks, children with autism have a good level of attention on average. However, these data should not be generalized to the entire clinical population, given that subjects with low levels of attention are usually excluded from experimental studies. More studies are needed to understand the relationship between attention and creativity.

Self-awareness and creativity in autism

Scientific research on creativity is often skewed by the fact that, in different subjects, external behaviours can be produced by different cognitive mechanisms. For this reason, Hobson et al. (2009) introduced an interesting dichotomy between *mechanics of pretend* and *playful pretend*. These experimenters observed and tried to measure some behaviours of children during spontaneous *versus* modelled play sessions in order to understand if the subjects had problems with the mechanical sequence of actions required by play sessions or with a more intentional interpretation of the act of playing. This is how the experimenters formalized this distinction:

- Mechanics of pretend:
  - Attribution of symbolic meaning to play objects
  - Flexible use of objects
- Playful pretend
  - Self-awareness in pretending
  - Investment in symbolic meanings
  - Creativity
  - Fun

Compared with the TD group, subjects with autism showed normal *mechanics of pretend*, but were significantly impaired in *playful pretend*. This was true both for the total score and for each of the individual subscales of playful pretend. When researchers compared the spontaneous with the modelled play sessions, they found that there were no differences between groups in the mechanics of pretend, but that playful pretend was significantly lower in subjects with autism in spontaneous play sessions under both conditions. However, researchers also found that, in subjects with autism, the modelled condition seems to increase playful pretend, especially the subscales of *self-awareness in pretending, creativity* and *fun.* In subjects without autism, on the contrary, modelled play sessions increase *self-awareness in pretending* and *investment in symbolic meaning*. Hobson et al. (2012) replicated the results for pretend (ToPP) play with a standardized test for play, adding a second comparison group with developmental disabilities. This time, experimenters found a correlation also between playful pretend and scores in communication and social interaction. These data are in line with some phenomenological descriptions of autism that put the accent on a lack of self-awareness (for a debate see Zahavi 2006: 215–222) in the clinical population.

Chronological age and other measurements

Two studies in our sample considered the chronological age of participants as a variable to be taken into account. Specifically, Jolley et al. (2013) compared their ASD group with a TD group matched for chronological age, a TD group matched for receptive mental age and a group of subjects with learning difficulties matched for receptive mental age. The creative performances of the TD group matched for chronological age with the ones of the ASD were significantly higher than in the other groups, even though the performances of the latter were not statistically significant. This means that, in order to compare creative performances between subjects with and without autism, the verbal age is more suitable than the chronological one (as for most other cognitive skills). Obviously, the reason is that autism is frequently associated with mental delay.

Weiss et al. (2014) used a more interesting matching method. They matched 12 children with AS (mean age = 7.65) and 12 adolescents with AS (mean age = 12.25) with two equally balanced TD groups. They also matched the participants for non-verbal intelligence. In this way, they found that the effects of age were significant in both groups (younger children performing worse), but were comparable across groups.

The meta-analysis confirms this hypothesis. We used the chronological age of participants (a mean of both the groups' age) as numerical moderator. Our null hypothesis was that the increase in age did not alter the relationship between the creative performances of the two groups. The scatter plot showed that the difference in the performance of subjects with and without ASD seems to decrease as the age of the participants increases ($Y = -0.1 + 0.01X$), but the trend is

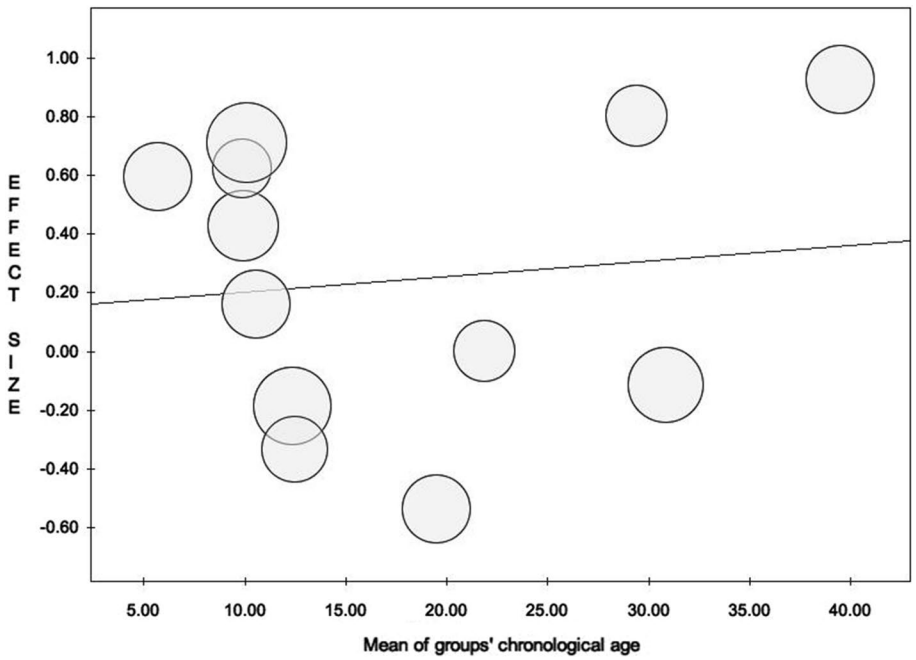

Fig. 9 Scatter plot of chronological age as numerical moderator. *Note*. The scatter plot indicates that the increase in age did not alter the relationship between the creative performances of the two groups

not statistically significant ($p = 0.719$; $\alpha = 0.1$) (cfr. Fig. 9). Thus, the null hypothesis was accepted.

None of the papers in our sample tested the relationship between creativity and memory/motor control/theory of mind or perception, so the analysis gave null results. Studies in this direction are needed.

In our meta-analysis, we made a meta-regression by using the publication year as numerical moderator. Our null hypothesis was that the publication year does not affect the difference in performance between the two groups. The scatter plot indicates that, in recent years, we have witnessed to an increase in the number of publications according to which the difference in performance between the two groups is lower than before ($Y = 338.01 - 0.06X$); however, this trend is not statistically significant ($p = 0.264$; $\alpha = 0.1$) (cfr. Fig. 10).

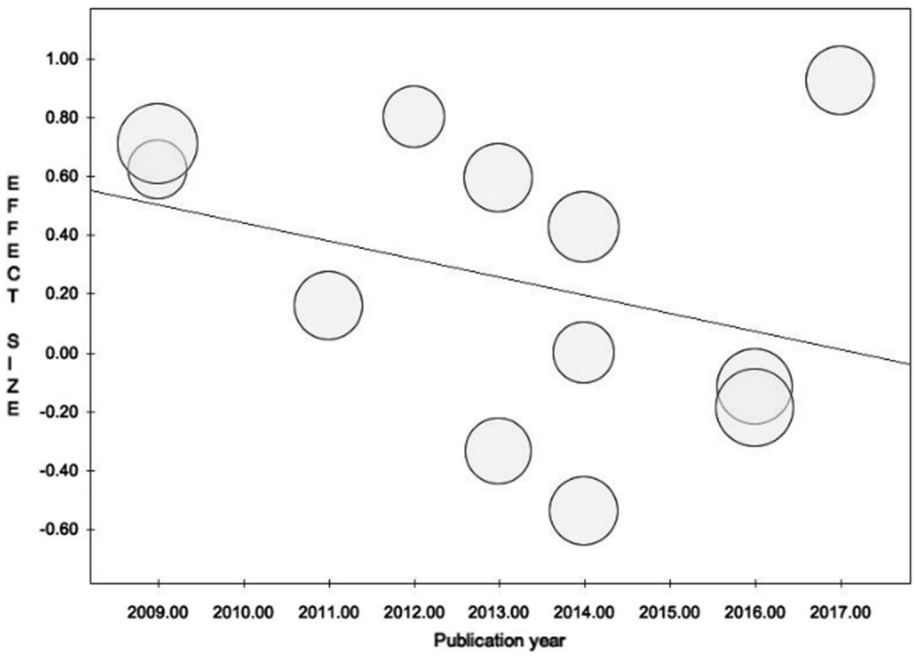

Fig. 10 Scatter plot of publication year as numerical moderator. *Note*. The scatter plot indicates that in recent years the number of studies that found differences in creativity between the autistic population and CG is lower than before. The trend is not statistically significant

Discussion

Our research produced three main outcomes. The first is that, when creativity is tested through cross-sectional studies, it is under-represented in the autistic population. These data are supported by both the systematic review and the meta-analysis ("Creativity is under-represented in theautistic population" section). The second is that subjects with autism score lower than CG in fluency and flexibility. (The data are confirmed by both the systematic review and the meta-analysis.) On the other hand, people with autism are not affected in elaboration and usually have higher scores in originality than CG (these data come from the systematic review, since the meta-analysis is inconclusive for elaboration and originality) ("How the type of task affects creativeperformances in subjects with autism" section). Lastly, creative performances in autism are greatly affected by linguistic skills ("A creative profile for subjects withautism" section).

Creativity is under-represented in the autistic population

Taken together, the psychometric studies included in our sample suggest that subjects with autism usually have lower scores in creativity than the rest of the population. These data are in line with the proposition 2 of the *mad-genius Paradox* put forward by Simonton (2014a, b): "*Proposition 1*: among all creative people, highly creative persons have higher rates of psychopathology than do less creative persons. *Proposition 2*: among all people, creative persons have lower rates of psychopathology than do non-creative persons" (Simonton 2014b: 471). Probably, as argued by Simonton, the studies in our sample account for creators at the lower end of the distribution of Lotka's law (Lotka 1926).

This theory would also provide a good explanation for the presence of eminent creators in the autistic spectrum ("Introduction" section) and is in line with the high rate of savant syndrome in the autistic spectrum. Simonton's theory, however, does not explain the discrepancies between the studies in our sample and, consequently, the high heterogeneity we found in the first outcome of the meta-analysis. As we will discuss in "How the type of task affects creativeperformances in subjects with autism" and "A creative profile for subjects withautism" sections, this heterogeneity can be partially explained by the kind of task used to test creativity and partially by the different notions of creativity that result from the characteristics we mentioned in "Performance-based meta- analyses" section: fluency, flexibility, elaboration and originality.

How the type of task affects creative performances in subjects with autism

We used the kind of test as categorical moderator for the meta-analysis, in order to understand if it could in some way explain the moderate heterogeneity of our results. With a moderate level of heterogeneity between studies, it seems that, when creativity is tested via linguistic tests, the performances of people with ASD are not statistically different from the ones of CG. However, since the confidence interval (CI) is positive and negative and above the line of significance in both cases, these data should be explained. The analysis of other outcomes is helpful in this respect. For example, the analysis of fluency reveals that subjects with autism are less fluent than subjects of CG in linguistic tests. These data are reinforced by the fact that, as we saw in "Language and creativity in autism" section and will discuss in "A creative profile for subjects withautism" section, higher level of linguistic skills has a predictive role of better creative performances for subjects with ASD than do lower linguistic skill levels; linguistic tests have a negative (significant) effect on originality (negative direction). Thus, in linguistic tests, it seems that subjects with autism are always less fluent but more original than subjects without autism. (Flexibility and elaboration were never been tested in our sample through linguistic tests.)

Data on visual tests indicate that, in visual tests, people with autism have lower scores than CG in creativity, fluency and flexibility. Data on elaboration and originality are too heterogeneous.

The difference in the outcome linked to performance fully explains the moderate heterogeneity of these data in the general creativity analysis. There is no heterogeneity in fluency: thus, data indicate that people with autism are less fluent in visual tests. There is a high level of heterogeneity in flexibility, but both the values of the CI are positive and above the level of significance. This means that all the studies in the sample agree in considering subjects with autism significantly less flexible than CG in visual tests. In other words, the disagreement is only on how inflexible people with autism are in these tests, not the fact that they are significantly inflexible in visual tests. These data are absolutely in line with the literature on autistic savants, such as Nadia ("A creative profile for subjects withautism" section), Gregory Blackstock, or Stephen Wiltshire.

Elaboration was evaluated through visual tests by two studies (Liu et al. 2011; Pring et al. 2012) which define elaboration as the quantity of details added to the images. However, they disagree on how much importance should be attached to various details such as the asymmetry of the figures.

Another difference between the two studies is probably linked to the groups they used. In fact, whereas Liu et al.

(2011) relied on an almost perfect matching between participants in verbal and non-verbal abilities, Pring et al.'s study (2012) compared 9 TD talented art students; 9 non-talented adults with mild/moderate LD; 9 savants with ASD; and 9 non-talented adults with ASD. While the PIQ was very similar among the last three groups, the VIQ was very different in all the four cases. In our meta-analysis, the scores considered were the mean values of talented art students and mild/moderate LD adults for CG and the mean values of the other two groups for the ASD group. However, a direct comparison of the savant group with the mild/moderate one revealed that the savant group has significantly higher scores in elaboration than the CG (Pring et al. 2012). On the other hand, a direct comparison of the ASD group with the mild/moderate one revealed that the latter scored higher than the former. Thus, higher skill levels in elaboration are more frequent when there is comorbidity between ASD and savant syndrome.

As regards the assessment of originality via visual tests, Pring et al. (2012) found that talented art students scored higher than all other groups. The other groups scored similarly, but savants scored higher than the other two groups. In this case, it seems that different levels of originality can be linked to different levels of PIQ or VIQ. As we better explain in "A creative profile for subjects withautism" section, it is plausible that higher linguistic skill levels do not have the same effect in the savant syndrome as in ASD.

For each outcome, the use of performative tests had at least a medium effect on autistic performances. (The effect was big for flexibility.) There are no discrepancies in these data; moreover, rigidity in the use of objects is a classical feature of subjects with autism. All the studies agree that subjects with autism are less creative than CG in performative tests. Data were confirmed for flexibility, fluency and elaboration. (No studies in our sample tested originality via performative tests.)

To sum up, people with ASD seem to be less fluent when tested through linguistic, visual and performative tests; less flexible when tested via linguistic and performative tests; their creativity is less elaborated when the test is performative. Subjects with ASD are not negatively affected in elaboration nor in originality when they are tested via visual tests. Subjects with autism are more original when they are tested via linguistic tests.

A creative profile for subjects with autism

The performance-based analysis of data suggests that subjects with autism are less fluent and flexible than subjects without autism in creative performances. The low level of fluency can be linked to the autistic's low level of social motivation (Chevallier et al. 2012); in other words, subjects with autism are probably less motivated to produce more answers because they are not interested in satisfying the researchers' requests. An alternative explanation could be that subjects with autism produce fewer answers because they are slower than CG in producing answers. That is, Carmo et al. (2017), by testing subjects with autism for categorical representation on visuospatial working memory, found intact performances but slower reaction times in subjects with autism than in the control group.

Even the low level of flexibility is totally in line with the cognitive profile usually associated with the diagnosis of autism. First of all, repetitive behaviours are frequently linked to cognitive inflexibility (Condy et al. 2019); moreover, the deficit in executive function causes cognitive inflexibility and is confirmed in the whole autistic population (Yasuda et al. 2014; Happé et al. 2006; Ozonoff and McEvoy 1994). Heterogeneity is low in fluency and in flexibility, but the CI is positive and above the level of significance: this means that studies agree on the significantly lower level of flexibility in people with autism, but disagree on the severity of this deficit.

Data on elaboration and originality should be discussed in greater detail. The systematic review indicated a good level of elaboration of creative ideas in subjects with ASD. The good level of elaboration (an example of which can be found in Pring et al. 2012; Fig. 11) is in line with the attention to details of subjects with autism (Baron-Cohen et al. 2009). This characteristic of autistic cognition is generally reported for visual stimuli, but has also been experimentally demonstrated for auditory stimuli (Bouvet et al. 2014). The popular perception of autistic talent is frequently linked to the high level of elaboration that subjects with autism are able to reach (consider, for example, the cases of Stephen Wiltshire, Gregory Blackstock and Nadia). Neither all creators with autism nor the participants of the studies in our sample reach high levels of detail. For instance, in the magnificent collection of drawings made by subjects with autism edited by Mullin (2014), both artworks that reach a high level of detail (i.e. Fig. 12) and artworks that do not reach such a level (i.e. Fig. 13) can be found.

Whereas the systematic review confirms this general perception of the autistic population, the meta-analysis reports a significant small effect in the opposite direction. Given that the effect we found is significant exclusively for performative tests, this discrepancy can be explained through the categorical analysis of moderator. In the two performative tests in the sample, in fact, the level of elaboration is linked to another skill that is usually affected in subjects with ASD: the pretend play. In our opinion, this is why subjects with ASD in our sample show low test scores in elaboration in the performative tests.

In visual tests, as we saw in "A creative profile for subjects withautism" section, savants scored very high in elaboration, whereas subjects with ASD without the savant

Fig. 11 Example of good level of elaboration. *Note*. Reported in Pring et al. (2012)

Fig. 12 David Barth: Vogels; 2008. *Note*. The author was 8 years old when he did this drawing; published by Mullin (2014), front cover

syndrome did not. An elaborate production takes into account the imperfection of reality more than the abstract ideas that are usually linked to it by culture. It is the level of detail with which a creator personally develops his idea. Let's consider how elaboration is declined in savant artists with ASD and, specifically, in the case of Nadia. Nadia was an autistic child with savant syndrome (Pennisi 2016a, b, c; Selfe 2011). When she was a child, she was very talented in drawing. Her drawings had a special contact with reality (cfr. Fig. 14). Nadia's cockerel is very elaborate and realistic. Nadia has clearly focused her attention on the cockerel's face, trying to replicate it twice more on the left of the main drawing. There is a very different level of elaboration between Nadia's drawing and the one

Fig. 13 Milda Banzaite; Peter; 2007. *Note*. Published by Mullin (2014)

she took inspiration from: for example, in the former a foot is missing and the tail is barely outlined, but the face has plenty of details, some of which are not even in the original drawing. Nadia's work is certainly imperfect due to the lack of some body parts, but is usually perceived as more realistic than cockerel C. This last, in fact, is also rich in details; these details, however, are more abstract. It is very symmetrical and prototypical. The boy who drew it covered the cockerel's body with feathers, but they are not very realistic. This is why cockerel B is usually perceived as more realistic than cockerel C. Despite this, a score for elaboration would not be adequately reflect of Nadia's accomplished performance because the missing foot and the missing parts of the tail would lower it.

Another interesting fact is that, when Nadia acquired language, she lost her talent. This event initiated a scientific debate (Pennisi 2016a, b, c; Selfe 2011). Some authors suggested that the acquisition of language was the cause of a diminishing of her perception and, consequently, of her talent. As we saw in "Language and creativity in autism" section, Constable et al.'s study (2017) suggests that subjects with ASD rely on their verbal abilities more than TD subjects while performing a creative task. If this is true, we could hypothesize that Nadia (who acquired very basic and simple language) lost her talent because, after she acquired language, she started to rely more on this than on her extraordinary visual perception of details, or that her own visual perception could have been diminished by the acquisition of language. This hypothesis is supported by the large number of savants with ASD with very poor linguistic skills. That is, Pring et al. (2012), who tested a group of 9 savants with autism, reported a very low VIQ in this group. Thus, it is possible that in the savant syndrome, the relationship between language and elaboration

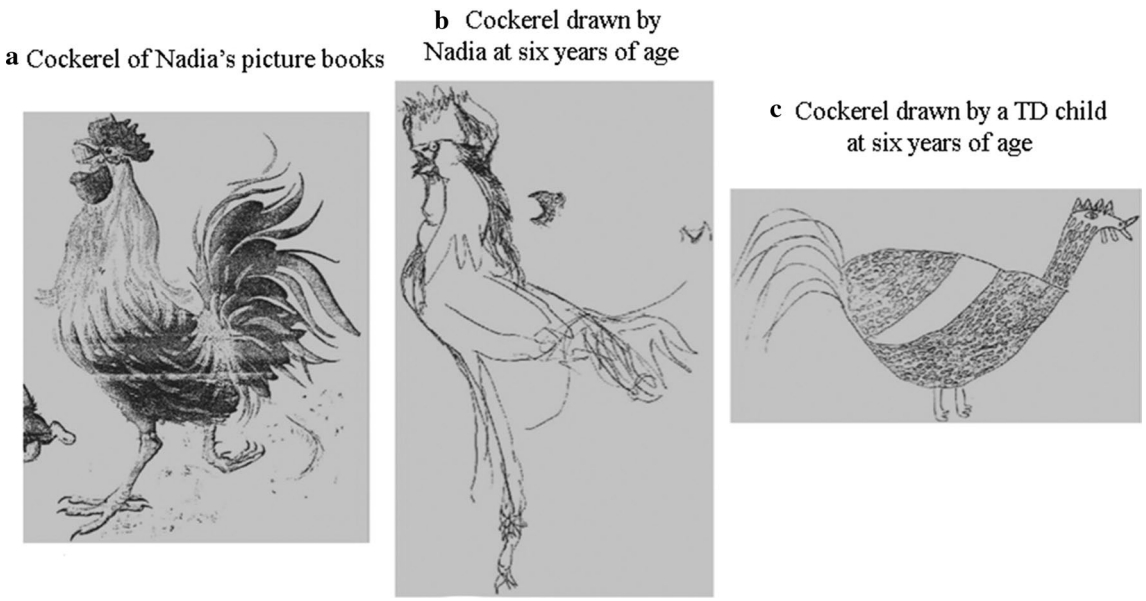

Fig. 14 Comparison of cockerel representations. *Note*. Picture A is the image from which Nadia drew inspiration for picture B. Picture B was a cockerel drawn by Nadia at 6 years of age. Picture C is a cockerel drawn by a talented six-year-old TD child. All pictures are taken from Selfe (2011). Nadia's cockerel is very elaborate and realistic. It is imperfect because it lacks one foot, but it is usually perceived as more realistic than cockerel C. Cockerel C too is indeed rich in details, but they are abstract details. It is very symmetrical and prototypical. This is why cockerel B is usually perceived as more realistic than cockerel C

is different from that of subjects with ASD without savant syndrome.

In experimental settings, groups are frequently matched for linguistic skills. It is likely that, in some cases, this kind of group matching produces a bias for elaboration. In other words: we think it is possible to find a high level of visual elaboration in subjects with autism and savant syndrome, who are usually excluded from experimental settings due to their very low linguistic skills.

If this hypothesis is true, the discrepancy between the studies carried out by Pring et al. (2012) and by Liu et al. (2011) is explainable as follows: in Pring et al. (2012), subjects with ASD without savant syndrome scored lower in elaboration than the other two CG because of their lower VIQ. Moreover, the VIQ level was very low in both groups. If it is true that higher linguistic skills have a protective effect on creativity that is higher in subjects with ASD (without savant syndrome) than in TD subjects, the difference between the VIQ of the two groups (even when reported as non-significant) must be determinant for the final results.

The high level of originality we found could be linked to numerous characteristics of the cognitive phenotype of the clinical population. For example, subjects with autism are usually non-conformists due to their lower level of social motivation (Chevallier et al. 2012). If, on the one hand, the low level of social motivation can affect fluency, on the other it makes subjects with autism more able to "think outside the box", an ability that Simonton (2014b) considers as one of the antecedents of creativity (see also Pennisi 2019; Carson 2014; Cardinal 2009). Another reason for the intrinsic originality of the art produced by subjects with autism could lie in their different perceptive style. It is well known that the perception of the face and the whole-perceptive biases linked to social cues that all typically developed subjects show are altered in subjects with autism (Brewer et al. 2017, 2019).

Although our sample does not include any study related to musical tasks, we have to recognize that music too is frequently considered a strength in autistic cognition (i.e. cfr. Heaton 2009) and that original musical compositions have been produced by subjects with suspected autism such as Erik Satie (Fung 2009) or Hikari Oe (Hesdorffer and Trimble 2016). Hence, musical strengths too could be explained through the relationship between anomalies in perception (Remington and Fairnie 2017; Kuriki et al. 2016) and originality.

Nevertheless, in the meta-analysis the high level of originality is associated with a high level of heterogeneity. The latter is partially explained by the differences in the various tests: subjects with autism are significantly more original in linguistic tests than in visual ones. In both cases, heterogeneity is high, and the confidence interval of significance is positive and negative and above the line of significance. The research on originality requires further studies.

The moderator regression of publication year was not significant, despite indicating a negative trend. This probably means that, over recent years, the creative strengths of people with autism have been more carefully evaluated by researchers.

To sum up, we believe that, when addressing the case of autism, it is more profitable to evaluate the four indexes of creativity in an independent way rather than thinking of creativity as a monolithic concept. According to this approach, subjects with autism are less fluent and flexible than CG, maintain a good level of elaboration and are more original than the rest of the population. At the beginning of our study, we asked ourselves if there was a relationship between autistic creativity and the cognitive phenotype of the spectrum and if it is possible to delineate a general cognitive profile for the autistic creator. Our study shows that the low level of fluency and flexibility as general cognitive characteristics of the population are actually also reflected in creative performances of subjects. Furthermore, our study highlights that two typical characteristics of autism, often considered deficits, namely (1) the tendency to develop manic fixations and to sometimes devote oneself for hours to a single activity and (2) the tendency to ignore the point of view of others, frequently become—in creative performances—two points of great value: originality and elaboration.

Cognitive characteristics of creativity in subjects with autism

Our analysis of the cognitive profile associated with creativity in autism leaves many open questions, but it is useful from both a pedagogical and a philosophical point of view. From a pedagogical point of view, it helps us to understand what abilities should be stimulated in order to improve the subject's creativity. For example, if it is true that language strongly predicts the ability of a subject with autism to express himself creatively, it is plausible that working on language might help him to express himself creatively. On the other hand, non-verbal intelligence and self-awareness also seem related to creative performances. Unfortunately, we still know too little about the relationship between creativity and executive functions, attention, motor control, memory, perception and theory of mind in subjects with autism. Therefore, until new data are produced in this direction, pedagogists need to acknowledge that the link between language and creativity and the one between non-verbal intelligence and creativity in subjects with autism seem to be quite solid.

From a philosophical point of view, something which appears relevant is that the relationship between the various cognitive processes and creativity seems to be different in subjects with autism, in those with typical development and

probably also in those with a comorbidity of autism and savant syndrome ("Language and creativity in autism", "A creative profile for subjects withautism" section).

Also, non-verbal intelligence seems to have a predictive role in the developing of creative skills in the clinical population ("Non-verbal intelligence and creativityin autism" section). Moreover, it seems that the clinical population is less self-aware than the control groups in creative performances ("Self-awareness and creativity inautism" section). Finally, the mean chronological age of groups seems not to affect the differences in the performances between the groups ("Chronological age and othermeasurements" section).

Other analyses conducted on the cognitive profile of the clinical population indicate that we need more data on the relationship between creativity and executive functions ("Executive functions and creativity inautism" section), memory, motor control, perception and theory of mind ("Chronological age and othermeasurements" section).

Limitations

Our sample is small. Moreover, we were not able to employ some studies because of methodological problems. That is, Kyaga et al. (2013), using a very large sample, found that autism was not over-represented among creative professions. This study is remarkable because it is a serious attempt to tackle the long-standing issue of the relationship between creativity and psychopathology from a quantitative point of view in a very large sample. However, the results cannot be considered an index of inhibition of creativity or of worse performances in creativity in subjects with autism in comparison with other control groups for two reasons. The first is that one of the parameters on which the creativity of the sample is assessed is the capacity to practise a creative profession during life; unfortunately, subjects with autism—creative or not—have greater difficulty in holding down a job because of their difficulties with social interactions. Moreover, the employment situation of subjects in the spectrum is better now than in the past decades. The second reason is linked to the definition of creativity: in fact, not all artists, writers or scientists (examples of professions considered to be creative, Kyaga et al. 2013) are creative and a lot of auditors or accountants (examples of professions not considered to be creative, *ibid.*) are creative (Dietrich 2014).

Another limitation of our sample is that none of the studies included in it tests musical, mathematical or poetical creativity. Such domains were partially assessed via self-reported questionnaire, but never through performance-based studies.

Moreover, whereas the hypothesis of a link between linguistic abilities and creative skills in subjects with autism seems to be well supported by our data, the link between fluency in creativity and language that we posited ("A creative profile for subjects withautism" section) is still speculative, since none of the studies in our sample directly tests this hypothesis.

Finally, a preliminary analysis prompted us to test different outcomes. Therefore, we added four hypotheses based on the analysis of performances (fluency, flexibility, elaboration and originality) to the first hypothesis (different level of creativity between the two groups). However, the sample for testing these hypotheses was always $k < 10$; then, we realized that the systematic review is more suitable than a meta-analysis to synthesize the state of the art. We made a comparison between the two methods, but when the data produced were discordant, we considered the systematic review to be more reliable.

Conclusions

Although more research is still required, we have reached the following conclusions. It seems that, in the average autistic population, there are fewer creative individuals than in the rest of population. However, we found that, in the case of autism, it is fruitful to investigate creativity as a complex phenomenon. By considering the four characteristics of creativity usually investigated in psychometric tests as four single items, we found that the average creative profile of subjects with autism has a marked inhibition of fluency and flexibility, a good level of elaboration and a strength in originality. Subjects with autism seem to reach higher levels of originality than the control groups.

Some papers in our sample (i.e. Pring et al. (2012) aimed to highlight the importance of considering these characteristics when evaluating the autistic creative profile. However, to our knowledge, this is the first time in scientific literature that such a thorough study has been conducted on the relationship between the different aspects of creativity and the different aspects of the autistic phenotype.

Moreover, we found that, when creativity is assessed via linguistic tests, there are no differences in the mean performances of subjects with ASD and CG. Better language skills appear to be linked to better creative performances. However, when there is a comorbidity of autism and savant syndrome, the relationship between language and creativity (specifically in elaboration) can follow different rules.

The data we found are interpretable through Simonton's mad-genius paradox (Simonton 2014a, b). Studies on autistic traits are still inconclusive. Further research is needed.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflicts of interest

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

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