Chapter 4

A Bibliometric Study on the Use of Virtual Reality (VR) as an Educational Tool for High-Functioning Autism Spectrum Disorder (ASD) Children

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Abstract

The use of virtual reality (VR) as an educational tool for autism spectrum disorder (ASD) children is a research field that started some 20 years ago. ASD is associated with deficiencies in communication and social interaction, as well as restricted and repetitive behavioural patterns, according to the fifth edition of the diagnostic and statistical manual of mental disorders (DSM-5). By using the ISI Web of Knowledge as the reference data basis, we perform a bibliometric study of the use of VR as an educational tool for high-functioning ASD children. By this study we can quantify, on the one hand, the up to day importance of the different types of VR applied to this field: immersive or non-immersive, as well as the use of human or agent avatars. On the other hand, we can also differentiate amongst those interventions that work on emotional and social competences. The analysis of periods of research scarce, research abundance and research trends provides a dynamic view of the strategies used in this field in the last 20 years and suggests future lines of research.

Keywords: virtual reality, ASD, bibliometric, education

1. Introduction

With constantly increasing prevalence rates, greater than 1% in countries such as USA [1], students with autism spectrum disorder (ASD) gradually acquire higher visibility, demanding research and development that provides new resources and strategies that meet their educational needs.

The fifth edition of the diagnostic and statistical manual of mental disorders (DSM-5) [2] characterizes ASD defining two main diagnostic criteria: the first category refers to impairments in

communication and social interaction whilst the second considers restricted and repetitive behavioural patterns. The DSM characterization of autism disorder has been traditionally accepted and considered a reference worldwide, but it has changed significantly throughout the different editions of the DSM since 1980. The DSM-III [3] was the first manual introducing "Infantile Autism" as a category within the "Pervasive Developmental Disorders" (PDD) domain. Seven years later, the revision of the DSM-III [4] renamed this category as "Autistic Disorder", eliminating age limits to its definition but still showing discrepancies with the International Statistical Classification of Diseases and Related Health Problems (ICD) criteria [5]. In 1994, the DSM-IV [6] was presented, maintaining "Autistic Disorder" as a PDD category, together with Rett Syndrome, Childhood Disintegrative Disorder, Asperger Syndrome and Pervasive Developmental Disorder—Not Otherwise Specified (PDD-NOS). A triad of impairments was defined, including social interaction deficits, verbal and non-verbal communication deficits and restricted and repetitive behavioural patterns, achieving great consistency with ICD criteria. The introduction of DSM-5 in 2013 eliminates all the sub-categories within PDD and the so-called ASD emerges as a new domain that encompasses the whole spectrum, in an effort to avoid stigmatization and controversy related to an excessive labelling. The aforementioned two main diagnostic criteria replaced de triad defined by the DSM-IV and several levels of severity were defined in order to distinguish between different profiles of the vast casuistry within the spectrum.

On the other hand, the use of virtual reality (VR) as an educational tool for students with ASD is a line of research that has been developing for more than two decades. Researchers agree that RV technology is especially suited to the educational needs of individuals with ASD [7–10]. This is so because through VR we can recreate any situation and social context, adapting and customizing it to the sensorial preferences of the student [11], as well as defining, controlling and manipulating the level and number of characteristics of verbal and non-verbal communication [12]. In addition, VR technology is aligned with the visuospatial preference that is generally identified as a strength and main learning channel of students with ASD. Furthermore, it allows for a systematic and repeated practice of tasks in very similar contexts to the real ones in the absence of potential risks [9, 10], also minimizing the associated fatigue to its realization in real contexts [13]. A typical discussion with regard to VR technology has to do with the level of immersion and sense of presence that it provides. Generally, immersive VR implies devices capable of displaying virtual environments that, at least visually, surround the user. This is normally identified with head mounted displays (HMD) or big screens or projections enclosing the user (CAVE). Nevertheless, some authors [14] distinguish different levels of immersion considering not just the visual experience but also the interaction with the virtual world that the system provides. Systems with movement recognition or data gloves allowing touching or moving virtual elements provide a quite remarkable sense of presence and are also considered immersive, even if visually they are not. Desktop VR, on the other hand, does not provide a great sense of presence, connecting the user with the virtual world through a window, generally the screen of a regular computer. Most of the research to date in this field has used desktop or non-immersive RV [15–18]. Although both non-immersive and immersive RV are shown as valid tools to serve as means in various areas of learning [19], both the realism of the virtual educational environment and the behaviour of the avatars or characters

with whom the user interacts socially, seem crucial to generate a sense of social presence, an aspect whose intensity is key for the experience of educational VR to be effective and transferable to the real world [20, 21].

Precisely, the interaction with other avatars within the virtual environment shows two completely opposed strategies [22]. Most of the research on the topic uses individual interaction [23–28], where the virtual avatars are computerized agents. This means that some kind of algorithm has been designed for them to react depending on the user's response, choosing a pre-designed answer. Unless an advanced artificial intelligent system is implemented it is difficult for this kind of strategy to recreate a fluid, realistic and natural social interaction. The other strategy is the so-called collaborative interaction, where real people are behind the virtual characters that interact with the user [29–35]. These human-avatars, depending on the features provided by the VR system, generally provide a more flexible, realistic and natural social communication, but needs for a real person to be behind the machine.

As for the abilities trained using VR technology for individuals with ASD, we can differentiate between research that promotes the learning of social skills [36–40], like safety protocols, socially accepted behaviour or motor and cognitive skills, and research that works on improving emotional competences [41–44], like facial cues and joint attention, emotions recognition and regulation or non-verbal language.

The present work tries to obtain a dynamic view of the scientific production on this field for the last 20 years, giving special attention to the main research strategies trends including type of VR used, type of virtual interaction applied and types of both social and emotional competences that these studies tried to improve.

The aim of the work presented here consisted in carrying out a bibliometric analysis about the state of scientific production with regard to the use of virtual reality (VR) as a learning tool for individuals with high functional autism spectrum disorder (ASD).

2. Method

In this paper we present a bibliometric study of the scientific production about the use of virtual reality as a tool for improving the behaviour of children with high functional autism (HFA) or Asperger. The time window used is 1996–2017, given that our search did not found contributions on this topic before 1996. The typical descriptive-retrospective design [45], following the usual stages of examination [46] was carried out, allowing us to select and organize the documentation.

2.1. Participants

The bibliographic consultation of the following databases: Web of Science, BIOSIS Citation Index, Current Contents Connect, Inspec, Medline, CINAHL and E-Journals, gave an initial

sample formed by 247 papers, published between 1996 and 2017. This initial sample was object of a work of individual reading, analysis of the data extracted, selection and classification throughout 2017, obtaining a final sample of 127 papers. The units of analysis were the computerized papers in English language, which dealt with the subject of virtual reality, autism, ASD, HFA and Asperger.

2.2. Design and procedure

We started by making a search for the available documents introducing the terms "Virtual and autism" or "Virtual and ASD" or "Virtual and Asperger" or "Virtual and HFA" in the topic search box, filtering by title, obtaining 247 results. The main research areas involved are, psychology, computer science, rehabilitation, education and educational research, engineering, communication and neurosciences. We did not filter by publication years, so that the window was automatically selected, from 1996 until 2017.

The next step was the traditional in bibliometric studies: (1) organization of the information according to the variables defined in **Table 1**. After discarding those papers duplicated or not related to the topic of research, a final sample of 127 papers was obtained; (2) selecting the bibliometric indicators specified in **Table 2**, that help to provide a first classification and quantification of the documents under study, differentiating between research documents and reviews, the type of virtual reality used, the type of interaction between user and avatar and whether the research aims to influence social or emotional competences; (3) finally, in order to provide a deeper picture of the main strategies of research conducted so far, a special classification was made defining both social and emotional skills sub-domains, as shown in **Table 3**.

Figures with descriptive statistics and frequency distribution are presented in order to systematize the selected variables and indicators.

Variables	Description
Paper	Title, year of publication, topic treated
Author/authors	Name of author/authors, professional profile, institution or centre where they work
Journal	Title of journal, thematic field of journal, database, impact factor, external reviewers
Language	English
Country	City and country
Competences treated	Social skills or emotional skills
Type of VR	Immersive VR or desktop VR
Type of virtual interaction	Individual or Collaborative (Avatar-Agent or Avatar-Human)

Table 1. Variables selected in the classification of documentary information about VR & ASD.

Bibliometric indicators	Description
1. Time-based scientific production	Evolution of scientific production related to VR & ASD through papers published during the period 1996–2017
2. Most productive journals in the field	Type of journals
3. Productivity by authorship and co-authorship	Most productive authorship and periods
	Most productive authors
4. Productivity rate with regard to citations	Number of citations and rate of citations per year received by the different works, placing special emphasis on the 10 most-oft-cited papers
5. Most productive countries	Countries with the highest productivity within the VR & ASD thematic field
6. Productivity related to main research strategy domains	Classification of productivity in the field with regards to social or emotional skills research, the use of desktop VR or immersive VR, the development of Individual or Collaborative interaction or the making of reviews
7. Research on intervention in social skills and emotional competences	Classification according to sub-domains of intervention in social skills and emotional competences amongst students with ASD using VR

Table 2. Specific bibliometric indicators about scientific production in relation to VR & ASD.

Social skills	
Safety	Safety measures like crossing the street, respecting traffic signals, driving or fire safety directives
Socially accepted behaviour	Trains appropriate behaviour in things like taking turns, respecting a cue, ordering in a restaurant, taking the bus…
Motor and cognitive skills	Depth perception, gestures, motor skills, sensory regulation, spatial navigation, visuospatial skills, audio-visual skills…
Emotional skills	
Facial cues and joint attention	Ability to process facial expressions, shifting attention, eye contact, engagement…
Emotions recognition and regulation	Identification of the emotional state of others (ToM), empathy, identification of their own emotional state, emotional regulation…
Non-verbal language	Body and facial non-verbal language, physiological signals

Table 3. Social and emotional skills sub-domains research strategies in relation to VR & ASD.

3. Results

Next we present the results obtained with the final sample of 127 papers according to the variables and indicators established.

3.1. Scientific production by year

Figure 1 shows the scientific production by year. This field started in 1996, and after a period with very few contributions, started again in 2002, progressively growing up to 2016. This growth is more pronounced from 2010 (5.5%), with a single year with a valley, 2012 (0.8%). The period between 2010 and 2017 comprises 80.4% of the papers on the subject. A maximum of 26 publications is reached in 2016, representing 20.5% of the total number of contributions.

3.2. Most productive journals in this thematic field

As **Figure 2** shows, the 6 most productive journals in this field out of the 84 results found are the following: Journal of Autism and Developmental Disorders (14.8%); Universal Access in Human-Computer Interaction (International Conferences) (8.6%); Computers & Education (3.9%); IEEE Transactions on Neural Systems and Rehabilitation Engineering (3.1%); Autism (2.3%) and Computers in Human Behavior (2.3%), all of them with at least 3 papers each. They cover 35.2% of the total of publications.

In the case of Journal of Autism and Developmental Disorders, 84.21% of the papers were published between 2010 and 2017—the most productive period for this thematic field. As for Universal Access in Human-Computer Interaction, 100% of its papers correspond to the International Conferences carried out between 2013 and 2016. The third most productive journal, Computers & Education, published 80% of its papers in the aforesaid period too.

3.3. Productivity by authorship and co-authorship

Figure 3 shows that works written by 2, 3, 4, 5 and 6 authors account for 71.6% of the whole sample studied; and a special mention needs to be made of papers with 3, 4 and 6 authors, which represent 47.2% of the sample. Importantly, 8.7% of the papers had 9 or 10 authors, something relatively strange, insofar as our analysis refers to a very specific subject where research tends to be carried out by small work teams.

Figure 4 shows which are the most productive authors, like Parsons, participating in 13 papers, 9 of them as first author, Lahiri, co-author of 10 papers, 7 of them as first author, Bekele, who shares 9 papers, 7 of them as first author and Strickland, involved in 5 papers, all of which as first author.

3.4. Productivity rate with regard to citations

Figure 5 shows the total number of citations received by the sample of 127 papers selected, distributed by their year of publication. 2011 is the year with most citations (14.5%), probably because many of the state-of-the-art reviews were published within this year. 2013 (12.9%) and 2002 (9.8%) follow 2011 as the years with most citations so far. Nevertheless, the real relevance of these figures depends on both the number of papers published every year and how old these papers are. The more years a paper has been available the more opportunities it had to be cited.

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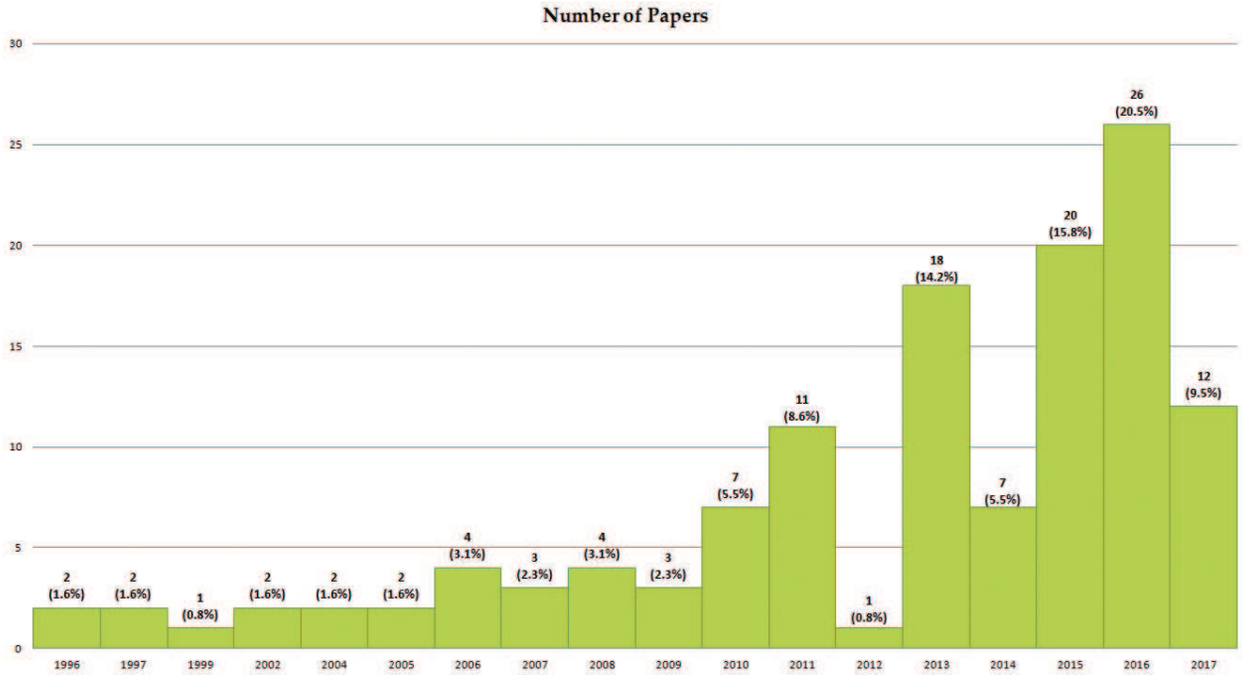

Figure 1. Number of papers on VR & ASD from 1996 to 2017.

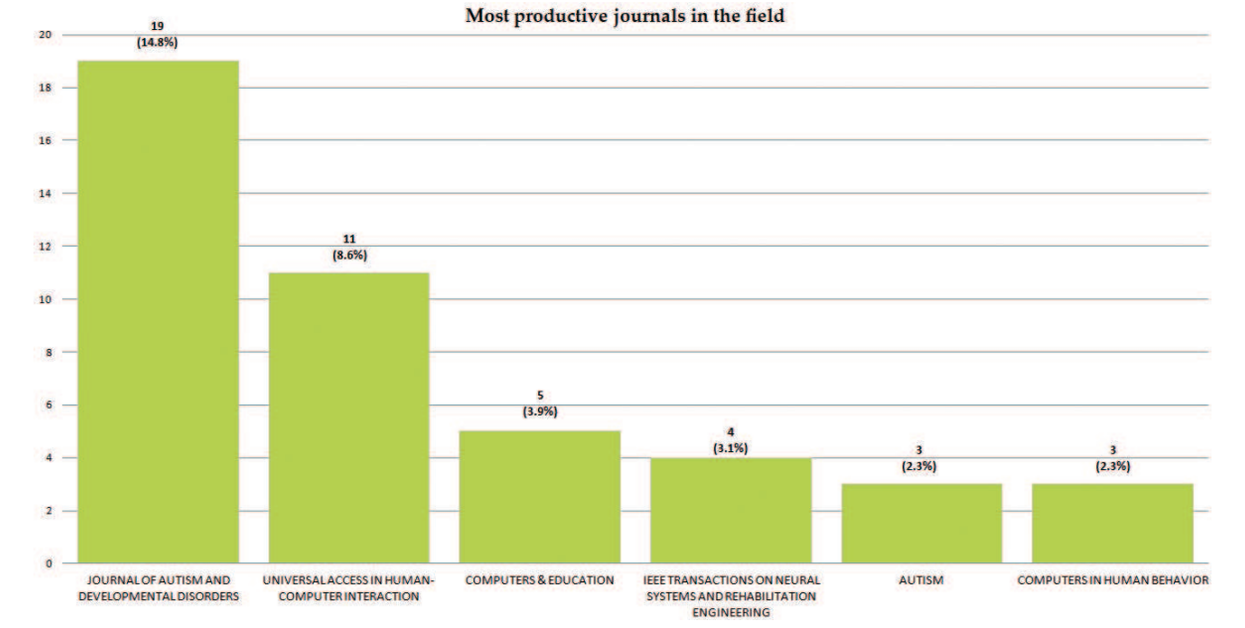

Figure 2. Six most productive Journals in thematic field.

Figure 6 depicts a more accurate picture of the productivity rate regarding to citations by showing the number of citations by year divided by the age of the papers cited. Citations ratio clearly grows from 2010 to date, with the only exception of 2012, a year strangely weak in research on this field. Even when 2013 (19.6%) and 2011 (14%) are still the years with best figures, the period from 2010 to 2017 comprises 76.9% of citations ratio, accumulating only 46.7% of total citations.

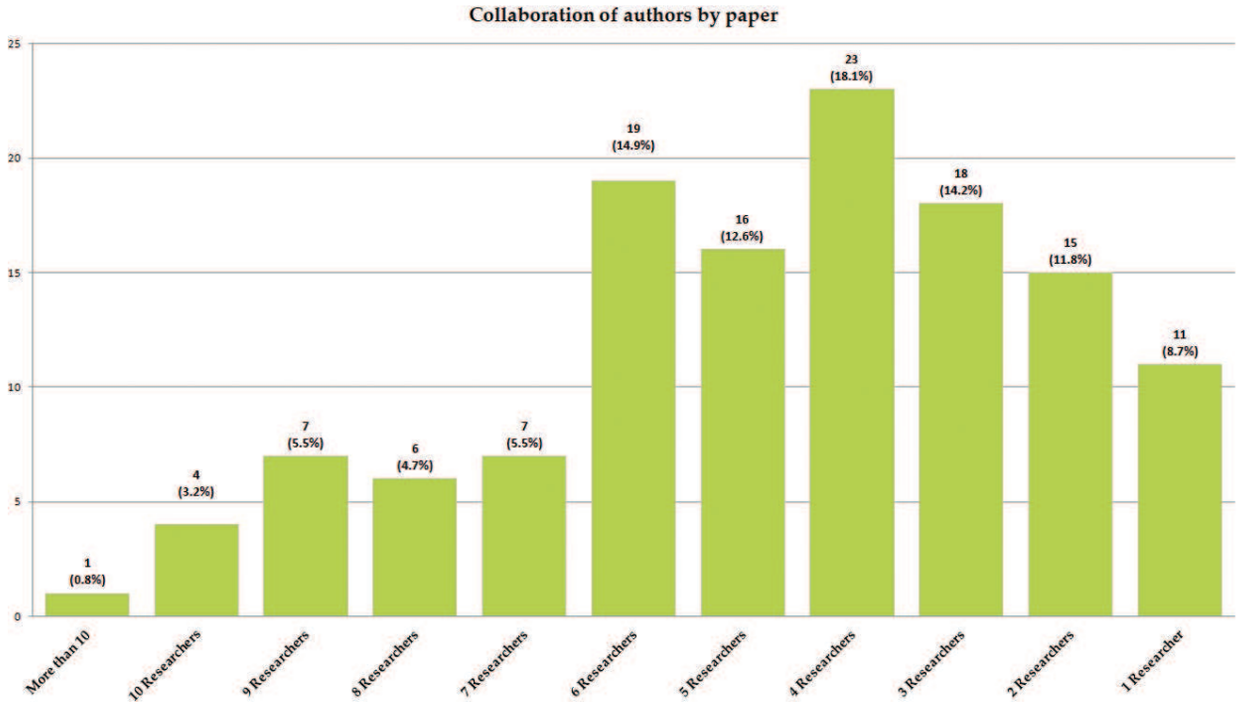

Figure 3. Collaboration of authors by papers.

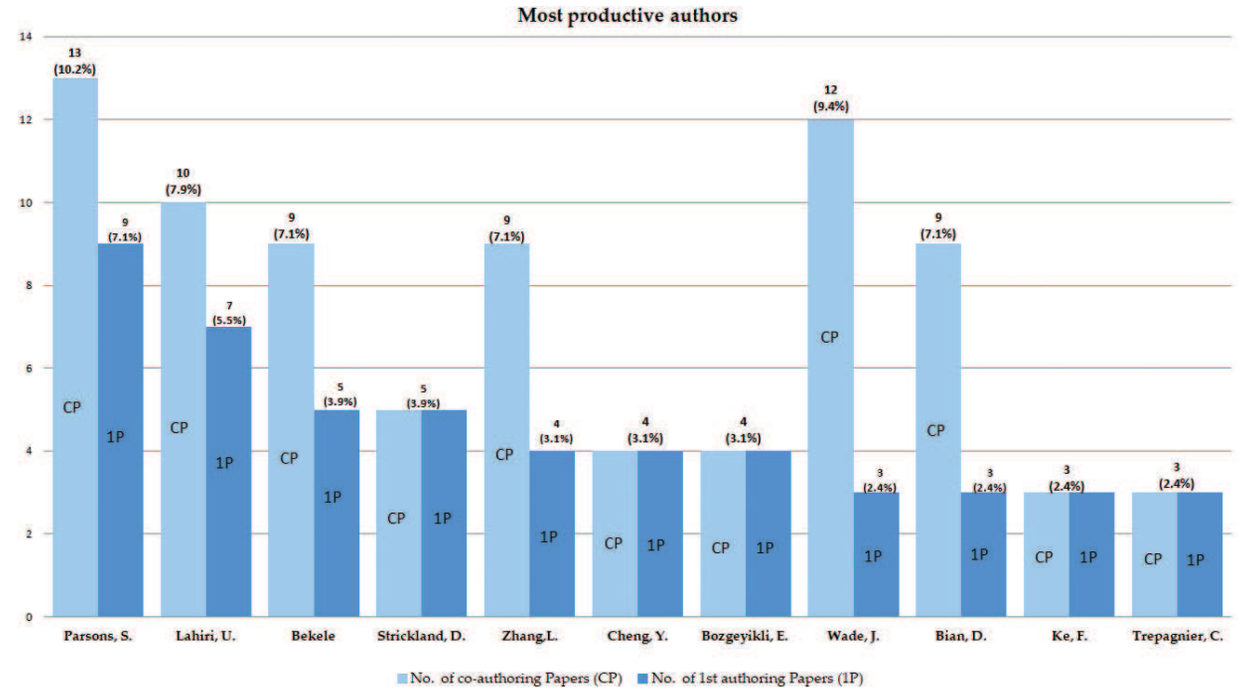

Figure 4. Most productive authors.

In **Table 4** we present the list of five papers that received more citations to date [9, 16, 24, 47, 48] together with the five papers with better citation ratio to date [16, 21, 28, 31, 49].

Only 1 out of the 5 most cited papers [16], with 254 citations, is part of the 5 papers that show a better citation ratio so far, showing a mean of 26.7 citations per year. The paper with most

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total citations is a review [9], with 307 citations, whilst the other 4 most cited are research papers on improving social skills for ASD individuals using VR [16, 24, 47, 48], with 254, 205, 187 and 185 citations as shown in **Table 4**. The paper with best citation ratio [31], with a mean

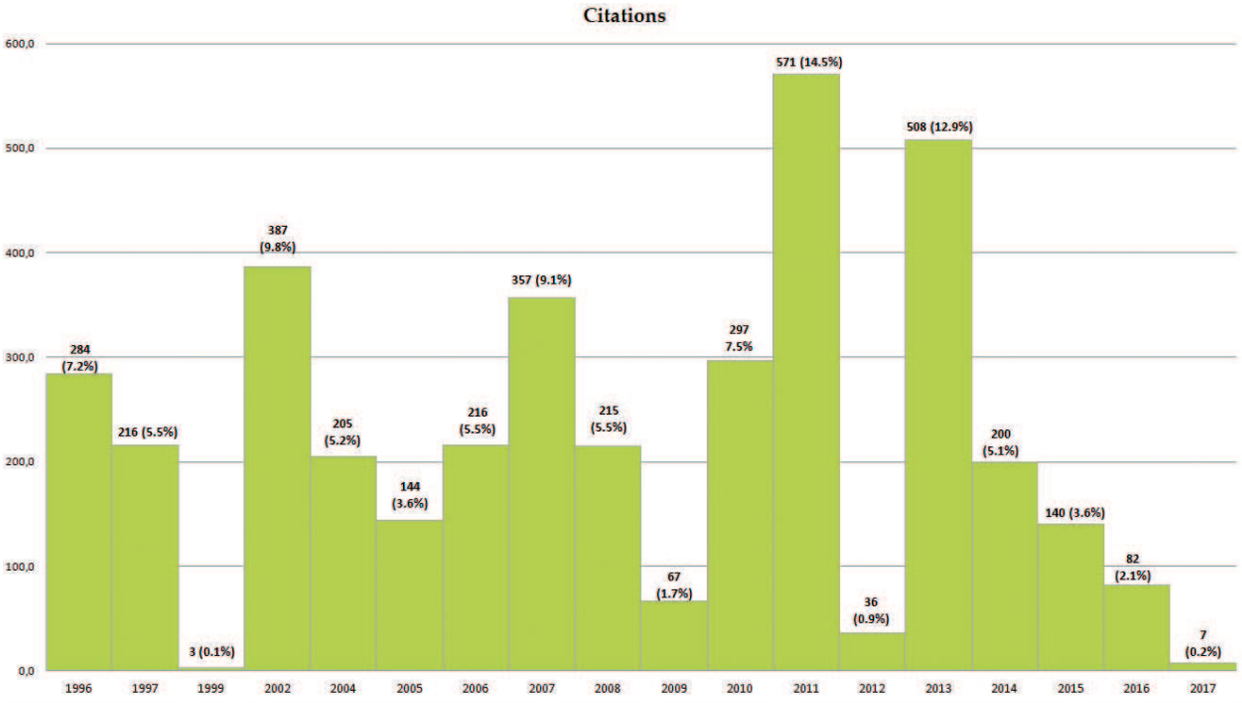

Figure 5. Total number of citations by year.

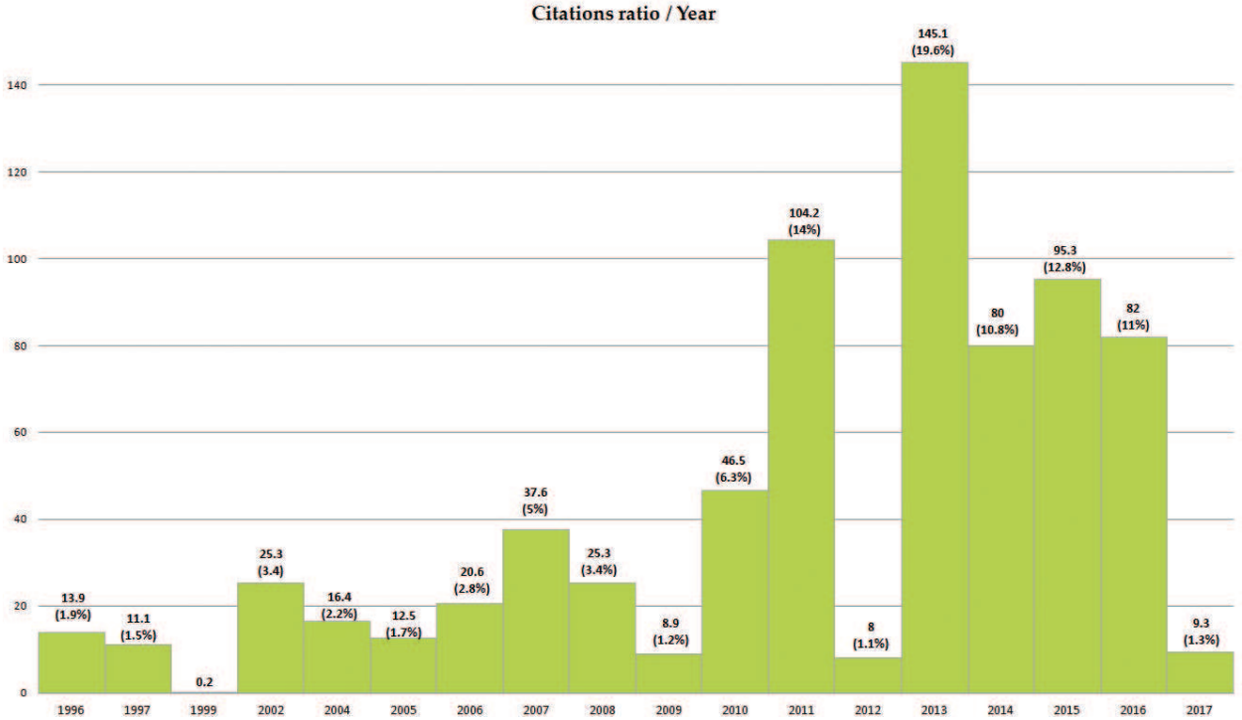

Figure 6. Citations ratio per year.

of 48.3 citations per year, is devoted to study both social and emotional skills of ASD people using VR. Two of the other four papers with best citation ratio are reviews [21, 49], showing both a mean of 21.6 citations per year, and the other two are research papers on improving social skills for ASD individuals using VR as well [16, 28], with means of 26.7 and 22.4 citations per year, respectively.

3.5. Most productive countries

Figure 7 highlights which countries showed a longer, more consolidated tradition in the treatment of ASD using VR. Out of 20 countries, 5 were selected for their higher productivity in this field. USA and UK produce about 67.7% of papers. The United States leads the ranking of largest producers with 65 papers—51.2% of the total—followed by UK (16.5%). India (4.7%), Spain (3.2%) and China (3.2%) lag far behind the top two countries, although only papers in English have been considered for this study.

3.6. Trends of research

In order to classify the research strategies within the reviewed literature, we now analyse the aforementioned contributions defining domains of research with regard to the content of the papers. **Figure 8** presents the six domains of research defined in **Table 2**, that is social or emotional skills research, the use of desktop VR or immersive VR, the development of Individual or Collaborative interaction and the making of reviews. Classification of productivity of each domain is quantified considering number of papers, citations mean per paper and citations mean per year per paper.

Paper	Type of paper	Citations	Citations ratio/year
Most 5 cited papers (values in bold)			
Parsons and Mitchell [9]	Review	**307**	21.2
Mitchell et al. [16]	Research on social skills	**254**	26.7
Parsons et al. [24]	Research on social skills	**205**	16.4
Strickland et al. [47]	Research on social skills	**187**	9.1
Strickland [48]	Research on social skills	**185**	9.5
Best 5 citations ratio papers (values in bold)			
Kandalaft et al. [31]	Research on social/emotional skills	169	**48.3**
Mitchell et al. [16]	Research on social skills	254	**26.7**
Smith et al. [28]	Research on social skills	56	**22.4**
Wang and Reid [49]	Review	119	**21.6**
Parsons and Cobb [21]	Review	119	**21.6**

Table 4. Most cited papers in relation to VR & ASD.

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Figure 7. Most productive countries.

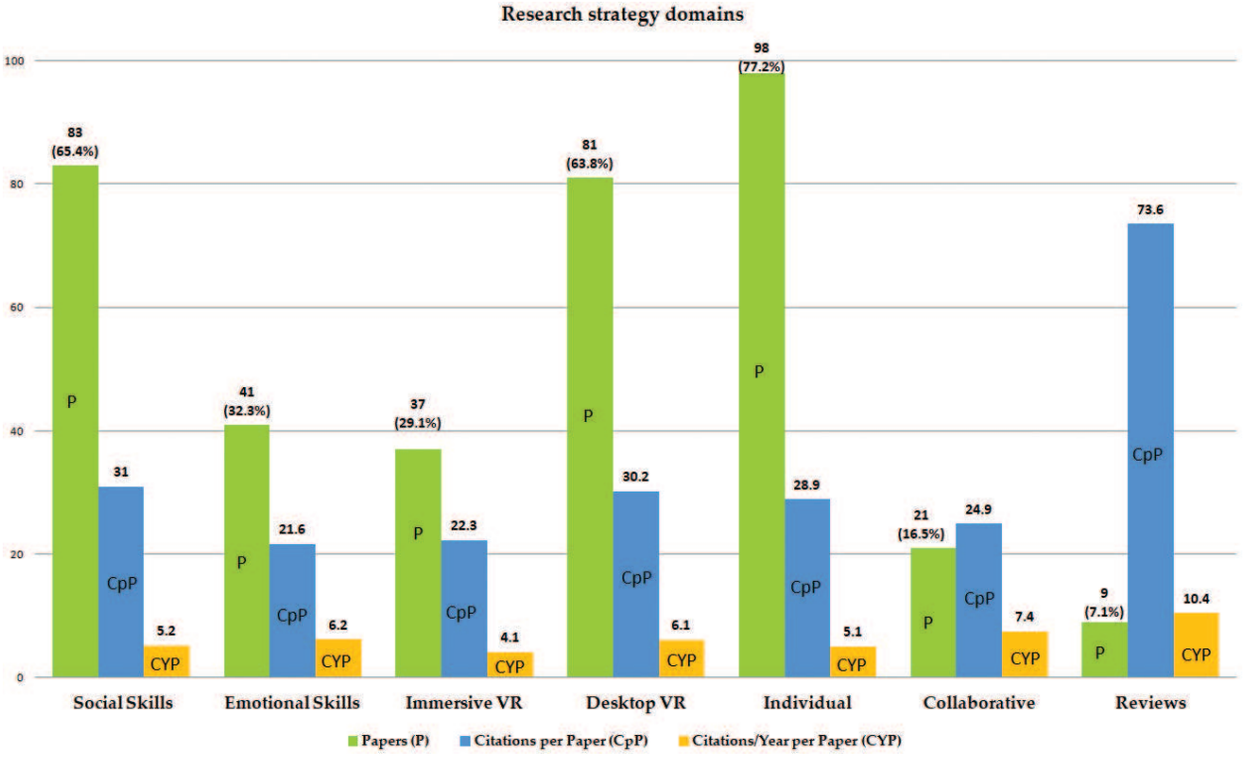

Figure 8. Research strategy domains.

The majority of the papers are devoted to the learning of social skills (65.4%), over those that deal with emotional skills (32.3%). Only 7.1% of papers are reviews. Individual interaction (77.2%) is clearly prevalent over collaborative (16.5%). As for the technology used, desktop VR (63.8%) overcomes immersive VR (29.1%). It is worth noting that for this study we have considered consistently the 127 papers revised as 100% of the sample in all cases, although six papers work on both social and emotional skills, and one paper utilizes both individual and collaborative interaction.

Nonetheless, if we consider citations, those papers devoted to social skills receive more citations per paper than those that work on emotional skills, whilst the latter show better citations ratio per year per paper. On the other hand, desktop VR papers show almost a third more citations per paper than immersive VR, which remains consistent with their ratio of citations per year per paper. As for individual interaction papers they show better ratio of citations per paper compared to collaborative interaction papers, whereas collaborative interaction papers present more citations per year per paper. Finally, as expected, the best citation picture appears in the reviews.

3.7. Social and emotional skills sub-domains

In order to get a better picture of the educational research strategies followed to date, we define several sub-domains within both social and emotional skills areas (**Table 3**). **Figure 9** shows a classification of productivity of each social skills research strategy area considering numbers of papers, citations mean per paper, and citations mean per year per paper.

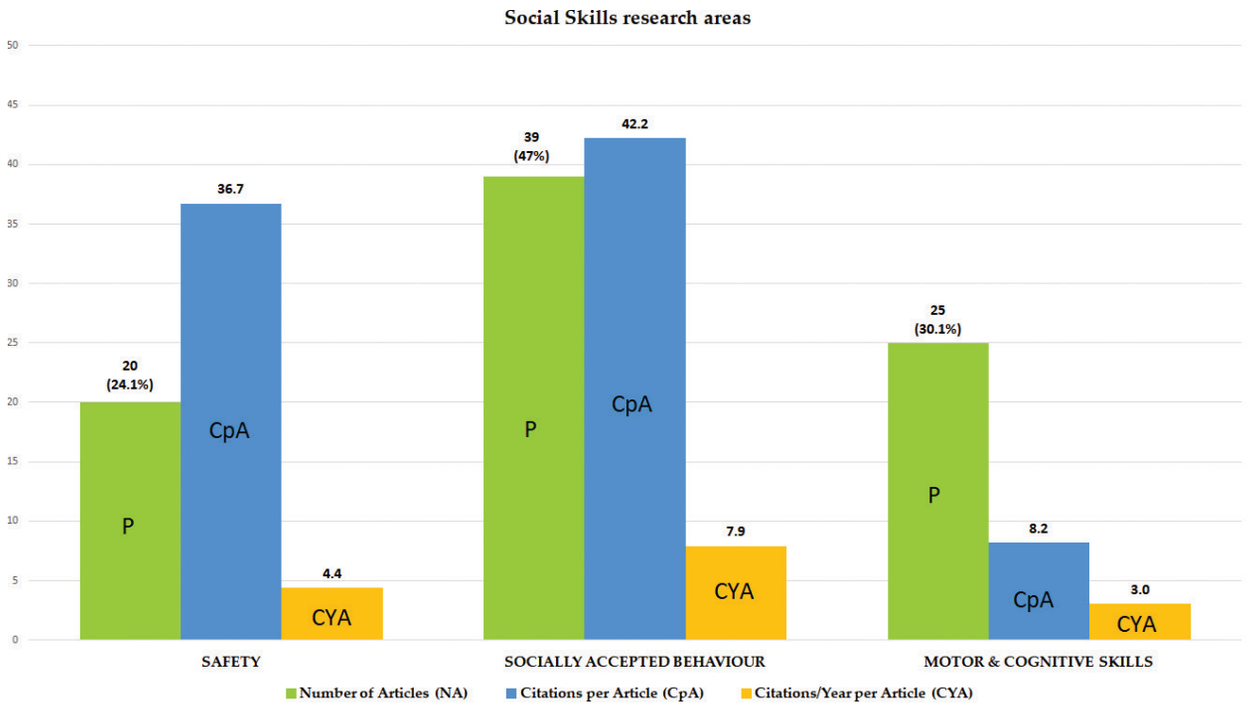

Figure 9. Social skills research strategy domains.

In social skills, the majority of papers are on "socially accepted behaviour" (47%), showing also the best citations ratio. "Safety" gathers slightly less papers (24.1%) than "motor and cognitive skills" (30.1%), but the first (36.7) more than quadruples the mean of citations per paper of the latter (8.2). Nevertheless, both "Safety" (4.4) and "motor and cognitive skills" (3.0) domains show similar citations ratio per year per paper.

Table 5 presents the three papers with best citation rate within the social skills sub-domains described in **Table 3** [16, 27, 28, 31, 47, 48, 50, 51]. One of these top citation rate papers [50] takes part both in "safety" and "motor and cognitive skills" areas of research. Both three top citation rate papers belonging to the aforesaid research sub-domains use immersive VR [27, 47, 48, 50, 51] whilst those papers with best citation rate within "socially accepted behaviour" research strategies choose desktop VR as educational tool [16, 28, 31]. Only one paper out of this list poses a collaborative virtual environment for social interaction [31].

Similarly, **Figure 10** shows a classification of productivity of each emotional skills research strategy area considering numbers of papers, citations mean per paper and citations mean per year per paper.

"Emotions recognition and regulation" area of research leads the number of papers on the subject (58.5%) followed by "facial cues and joint attention" (41.5%) and "non-verbal language" (7.3%). Surprisingly, "facial cues and joint attention" (24.1) shows the best citations mean per paper of the three domains at stake, whilst "emotions recognition and regulation" (6.1) maintains the best citation ratio per paper per year, although "facial cues and joint attention" (5.4) presents a similar figure on this matter. "Non-verbal language" research domain lags far behind both in number of papers (7.3%) and citations rate (3.2).

Article	VR type	Type of interaction	Citations	Citations/year
Safety				
Saiano et al. [50]	Immersive (BS*)	Individual	15	**10.0**
Strickland [48]	Immersive (HMD*)	Individual	185	**9.5**
Strickland et al. [47]	Immersive (HMD*)	Individual	187	**9.1**
Socially accepted behaviour				
Kandalaft et al. [31]	Desktop	Collaborative	169	**48.3**
Mitchell et al. [16]	Desktop	Individual	254	**26.7**
Smith et al. [28]	Desktop	Individual	56	**22.4**
Motor & cognitive skills				
Saiano et al. [50]	Immersive (BS*)	Individual	15	**10.0**
Lorenzo et al. [27]	Immersive (CAVE*)	Individual	31	**8.9**
Greffou et al. [51]	Immersive (CAVE*)	Individual	36	**8.0**

*HMD = head mounted display; BS = big screen.

Table 5. Best citations rate articles (values in bold) within the social skills sub-domains.

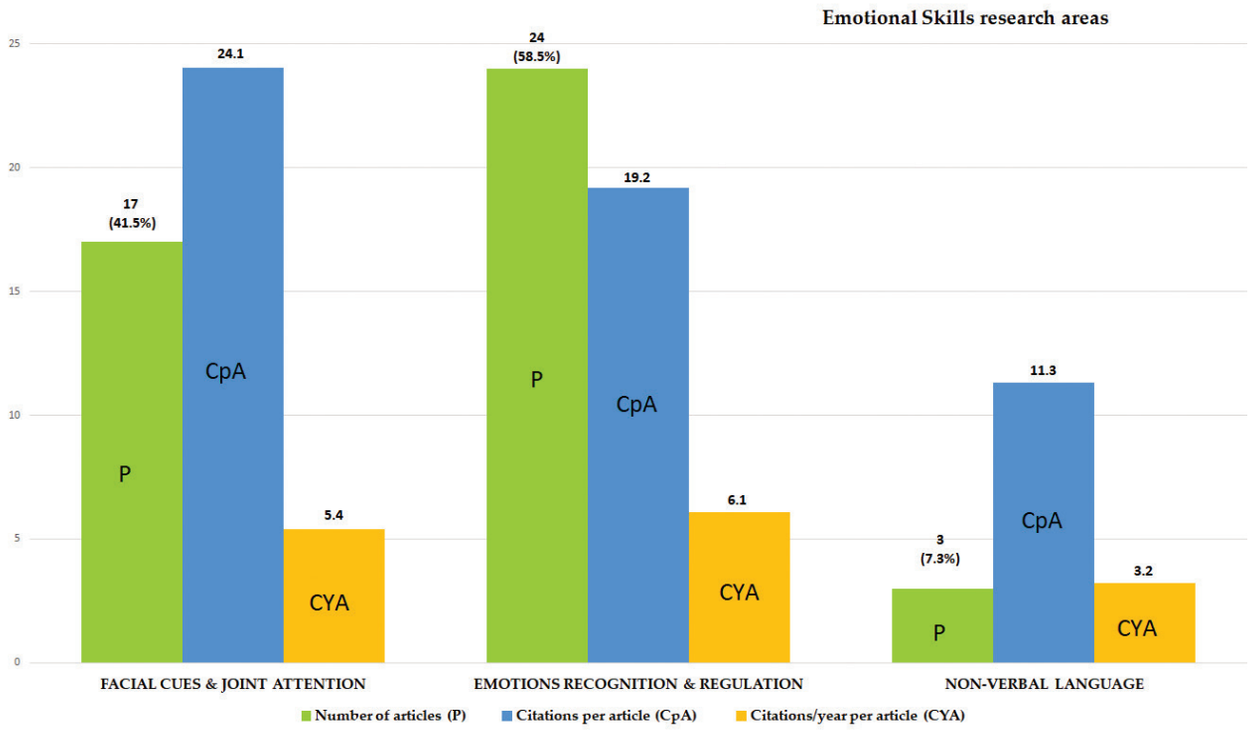

Figure 10. Emotional skills research strategy domains.

Table 6 presents the three papers with best citation ratio within the emotional skills sub-domains described in **Table 3** [31, 52-59]. All nine papers use desktop VR as learning tool. Two papers of this list belonging to "emotion recognition & regulation" research sub-domain utilize

Article	VR type	Type of interaction	Citations	Citations/year
Facial cues & joint attention				
Lahiri et al. [52]	Desktop	Individual	55	**15.7**
Lahiri et al. [53]	Desktop	Individual	75	**13.6**
Bekele et al. [54]	Desktop	Individual	44	**12.6**
Emotions recognition and regulation				
Kandalaft et al. [31]	Desktop	Collaborative	169	**48.3**
Didehbani et al. [55]	Desktop	Collaborative	17	**17.0**
Cheng et al. [56]	Desktop	Individual	75	**11.5**
Non-verbal language				
Kuriakose and Lahiri [57]	Desktop	Individual	8	**5.3**
Schwartz et al. [58]	Desktop	Individual	24	**3.7**
Kuriakose et al. [59]	Desktop	Individual	2	**0.6**

Table 6. Best citation rate articles (values in bold) within the emotional skills sub-domains.

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collaborative virtual interaction [31, 55]. One of these two papers is also part of the list of papers with best citations ratio within social skills, as it works both emotional and social competences [31].

4. Discussion

The aim of the work presented here consisted in carrying out a bibliometric analysis about the state of scientific production with regard to the use of virtual reality (VR) as a learning tool for individuals with high functional autism spectrum disorder (ASD). Virtual reality provides a safe customizable learning environment where ASD students are able to repeatedly practice and develop their social and emotional competences. This field of research, which started more than 20 years ago, has obviously been conditioned by both the VR technology development and all the substantial changes that have occurred over this period with regard to the categorization of ASD. The present study has enabled us to quantify some clarifying results about the understanding and evolution of this topic of research. First of all, the scientific production in this field is rather small considering its relatively wide trajectory. As for the variables selected when classifying the documentary information about VR and ASD and the bibliometric indicators chosen, it is worth highlighting that most of the scientific production is concentrated between 2010 and 2017. This probably has to do both with the level of development and affordability of the VR technology and the capability of adopting strategies to use it as a learning tool for ASD individuals.

The journal with the largest concentration of papers is the Journal of Autism and Developmental Disorders with 19 papers, whilst the second source corresponds to International Conferences, Universal Access in Human-Computer Interaction. In both cases the large majority of published research corresponds to the period 2010–2017. The fact that an international conference accumulates a significant part of the scientific production within our sample means that this is a topic that has been debated with a growing interest amongst researchers in the field during the last years. In dealing with co-authorship, it is worth mentioning that papers written by 2, 3, 4, 5 and 6 authors account for 71.6% of the whole sample studied; and a special mention needs to be made of papers with 3, 4 and 6 authors, which represent 47.2% of the sample. There are also a few papers involving 9 or 10 authors, maybe indicating that larger team groups start to deal with the topic, due to its multidisciplinary characteristics, involving technicians related to the VR technology, together with psychologist and educational therapists.

As for citations, we distinguish between total number of citations and citation ratio per year. Taking into account the sample size it is worth considering both indicators that serve the purpose of highlight the concentration of interest in the papers as well as in the research strategies. The most cited paper is a review [9], whilst the next most cited papers are both devoted to social skills[16, 24].These three most cited papers are authored by Parsons, Mitchell and Leonard, highlighted as influential pioneers on this topic of research. Nevertheless, it is also worth mentioning that the paper with the highest citation ratio [31] deals with both social and emotional skills utilizing collaborative interaction, showing that relatively recent research working on a wide range of competences and recreating a more natural interaction sparks the interest of other researches in the field.

If we look at the countries with the largest production, the United States of America clearly stands out from the rest, followed by the United Kingdom. India, Spain and China appear immediately after. Of course, the fact that the selected language was English influenced this result.

It is worth mentioning that the sample selected presented an approach based on educational and pedagogical interventions rather than from a psychological perspective, whilst the vast majority of studies on high-functioning ASD belong to the behavioural sciences area [60]. This fact, together with the specific use of virtual reality as an educational tool may also explain the sample size, since the pedagogical treatment of the topic is rather new.

Regarding the six domains of research, namely social or emotional skills research, the use of desktop VR or immersive VR, the development of Individual or Collaborative interaction and the making of reviews, we observe that the amount of papers devoted to the learning of social skills strongly dominates those that deal with emotional skills. Similarly, papers using individual interaction clearly prevail over those using collaborative, and desktop technology strongly overcomes immersive VR. We may say that the typical paper deals with social skills, uses desktop technology and individual interaction. Not surprisingly, papers lying in the prevalent domains of research receive more citations. Nevertheless, we also perceive a turning interest towards emotional skills and collaborative interaction when looking at the ratio of citations per year per paper, that overcome those of social skills and individual interaction. The explanation may rely on the turning importance given in ASD classification to emotional skills as well as in the lately availability of affordable technology, also related with the late emerging of more papers using immersive technology, even though they are still far away from desktop.

Only 7.1% of papers are reviews, but they have a very good citation record. This is quite normal, since reviews are a source of interest, not only for established researcher but also for anyone starting in the field.

Finally, an interesting picture emerges when analysing more in deep the sub-domains within social and emotional skills. In dealing with social skills, "socially accepted behaviour", is the sub-domain with most papers, showing also the best citations ratio, probably due to the fact that it comprises a wider range of competences. "Safety" gathers slightly less papers than "motor and cognitive skills", but the first more than quadruples the mean of citations per paper of the latter. Nevertheless, both "safety" and "motor and cognitive skills" domains show similar citations ratio per year per paper. One of top citation rate papers belong both to "safety" and "motor and cognitive skills", showing also a certain turning into more practical skills in the late years. Also, the best citation rate papers use immersive VR, whilst those papers with best citation rate within "socially accepted behaviour" research strategies choose desktop VR as educational tool.

In the case of emotional skills, "emotions recognition and regulation" area of research leads the number of papers on the subject, closely followed by "facial cues and joint attention". "Facial cues and joint attention" shows the best citations mean per paper of the three domains at stake, whilst "emotions recognition and regulation" maintains the best citation ratio per paper per year, although "facial cues and joint attention" presents a similar figure on this

matter. In this area, thus, these are the two sub-domains receiving more attention from the researcher. "Non-verbal language" research domain lags far behind both in number of papers and citations rate. All the most cited papers in the whole area use desktop VR as learning tool. Two papers of this list belonging to "emotion recognition & regulation" research sub-domain utilize collaborative virtual interaction. One of these two papers is also part of the list of papers with best citations ratio within social skills, as it works both emotional and social competences.

In spite of the effort we made in classifying the different strategies used, we may say that the sample size does not allow us to obtain strong conclusions on the main trends of research. The design and development of the different virtual environments (VE) needed to conduct research to improve the social and emotional competences of ASD individuals is a high-effort task, and whether it is true that some designs have been shared in different research projects or already are open-access tools [12, 29, 31], it is also true that a great deal of papers imply the develop of their new ad-hoc VE scenario. This is understandable, considering the wide range of possible skills to be tested and improved, and the wide range of ASD cognitive styles with their particular special educational needs. Nonetheless, in a promising and emerging field, the promotion of growing synergies is highly recommended. Creating a VE repository for researchers to have at hand would ease the research processes and the possibility of producing better reliable comparable results.

5. Conclusions

Summarizing, we may say that from this study we observe an increasing interest in the topic "Virtual Reality as an educational tool for High Functioning ASD children" since 2010; with significant prevalence of studies on learning social skills, using individual interaction and desktop technology; that nevertheless, the use of immersive technology and collaborative interaction are strongly increasing and also there is a tendency to deal more frequently with emotional competences. It is interesting to remark that the current availability of affordable VR technique as well as the increasing capabilities to offer new applications will most likely increment the power of VR as an educational tool. The use of this technology for ASD children seems to be extremely promising and may well become a standard educational instrument for this population in the future. The best way of so doing clearly involves the need of creating interdisciplinary research teams to fully exploit the capabilities of the technology as a tool to overcome both social and emotional handicaps in ADS children.

Next we highlight the main conclusions:

- The scientific production in this field is rather small considering its relatively wide trajectory, mostly concentrated between 2010 and 2017.
- The United States of America is the country with the largest production of papers, followed by the United Kingdom. Journal of Autism and Developmental Disorders is by far the journal with most production on the topic of research.

- In dealing with the strategies used, we may say that the typical paper deals with social skills, using desktop technology and individual interaction. The most cited papers belong to these categories.
- We nevertheless perceive a turning interest towards emotional skills and collaborative interaction when looking at the ratio of citations per year per paper, that overcome those of social skills and individual interaction.
- Only 7.1% of papers are reviews, but they have a very good citation record.
- In dealing with social skills, "socially accepted behaviour", is the sub-domain with most papers, showing also the best citations ratio.
- The best citation rate papers in "safety" and "motor and cognitive skills" use immersive VR, whilst those papers with best citation rate within "socially accepted behaviour" research strategies choose desktop VR as educational tool.
- In the case of emotional skills, "emotions recognition and regulation" area of research leads the number of papers on the subject, closely followed by "facial cues and joint attention".
- The promotion of synergies within researchers in the field would boost the production and quality of the results obtained. Creating a VE repository for researchers to have at hand would ease the research processes and the possibility of producing better reliable and comparable results.

The main limitation of our research deals with the sample size, but this is nothing but an outcome of the novelty and specificity of the topic. Nonetheless, we feel that our main conclusions are robust enough, signalling the trends for future research.

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