Advances in Neurodevelopmental Disorders (2023) 7:290–299
https://doi.org/10.1007/s41252-023-00318-5

ORIGINAL PAPER

Robots, Neurodevelopmental Disorders, and Psychology: a Bibliometric Analysis and a Case Made for Robopsychology

Christian U. Krägeloh[1] · Jaishankar Bharatharaj[2] · Marcel Heerink[3] · Daniel Hannon[4] · Jordi Albo-Canals[5]

Accepted: 17 January 2023 / Published online: 13 February 2023

Abstract

Objectives Robots have the potential to enable new ways to improve the lives of people with special needs. This bibliometric review explored the nature of research that had referred to robots in the context of neurodevelopmental disorders and psychology, outlining the range of research areas, most prolific researchers, outlets for research dissemination, and trends.

Method Using the database Scopus, publications were identified that mentioned in the abstract robot as well as one of several common neurodevelopmental disorders. Results were analyzed and visually presented using the software VOSviewer. An additional search identified publications about robots in the context of psychological research more broadly.

Results Studies about autism spectrum disorder and social communication skills were the most frequent. Much of this work is disseminated as publications related to engineering and neuroscience, which is also consistent with the background of the most prolific and cited researchers of this bibliometric search. A notable trend is the increasing role played by psychology in robotics research.

Conclusions Research work on robots in the context of neurodevelopmental disorders and psychology has traditionally been developed by researchers with a background primarily in engineering and computer science. As psychology is getting ready to play a more prominent role, there is a chance to apply specific psychological theory and methods. Such application may be facilitated by the establishment of a relevant scientific infrastructure, such as through a specialist journal on robopsychology.

Keywords Robots · Neurodevelopmental disorders · Bibliometric analysis · Psychology · Robopsychology

As technology advances, the scope of application of robots continues to expand rapidly. Aside from industrial (Arulkirubakaran et al., 2022) and surgical (Cepolina & Razzoli, 2022) uses of robotic technology, robots are now increasingly used in educational settings (Chu et al., 2022; Marcos-Pablos & García-Peñalvo, 2022), for entertainment (Pratticò & Lamberti, 2020), and in the hospitality industry (Rosete et al., 2020). With increased functionality, robots are also starting to become an attractive tool to address people's psychosocial needs. The companion robot *Paro*, for instance, possesses an attractive morphology of a seal with soft fur and big eyes. When stroked, it can provide vocal feedback or respond with limited movements. In a 5-year longitudinal study, interaction with Paro was reported to improve mood and to decrease depression and stress in residents of an aged care facility in Japan (Wada et al., 2009). In a randomized controlled trial conducted with residents of a rest home in New Zealand (Robinson et al., 2013), exposure to Paro for an hour a week over a 12-week period was associated with decreased loneliness. Outcomes were similar to those reported when interacting with the resident dog, although the residents indicated that they were more willing to touch the robot.

✉ Christian U. Krägeloh
chris.krageloh@aut.ac.nz

1 Department of Psychology and Neuroscience, School of Clinical Sciences, Faculty of Health & Environmental Sciences, Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand

2 PAIR Lab, Bharath Institute of Higher Education and Research, Chennai, India

3 Saxion University of Applied Sciences, Enschede, Netherlands

4 Tufts University, Medford, MA, USA

5 Lighthouse Disruptive Innovation Group, LLC, Cambridge, MA, USA

Other studies have explored the utility of robots for interventions designed to assist individuals with neurodevelopmental disorders such as autism spectrum disorder (ASD). In their systematic literature review, Damianidou et al. (2020) analyzed 39 studies that reported on some form of robot-mediated intervention to improve communication and social interactions of people with ASD. Most of these studies reported that the use of robots in interventions was successful in improving social skills, often measured by eye contact and joint attention. A common robot used was the humanoid *Nao* robot. For example, So et al. (2019) assigned autistic children to either a human-based or a robot-based intervention group. In the former group, two human demonstrators engaged in a series of verbal exchanges in front of the children. Each demonstrator would say one sentence whereby the second demonstrator accompanied the sentence with 1 of 14 gestures (e.g., saying "I would say bye-bye…" and then waved). When the same verbal and gestural interactions were performed by two Nao robots, the children were subsequently equally likely to recognize and produce the gestures than the children in the human-based intervention group.

Robots used in therapeutic settings are often a type of social robot. A social robot has been defined as "an autonomous or semi-autonomous robot that interacts and communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact" (Bartneck & Forlizzi, 2004, p. 592), although in most studies the technology is only sufficient for the appearance of autonomy rather than possessing autonomy in the naturalistic sense (Cowley & Gahrn-Andersen, 2022). Apart from ASD, social robots have been used as therapeutic tools for a number of health conditions, including attention-deficit hyperactivity disorder (ADHD), depression, and schizophrenia (Guemghar et al., 2022). While bibliometric data has previously been published about research trends and the knowledge base for social robotics (Mejia & Kajikawa, 2017), little is known about the nature of the research that applies robots to the context of neurodevelopmental disorders. The available data for social robotics indicate that much of such research work appears to be published as conference proceedings for disciplines such as computer science or human–robot interaction (Mejia & Kajikawa, 2017). Krägeloh et al. (2022) observed that there is currently a lack of psychology journals specifically dedicated to research on human interactions with robots, begging the question as to how work on psychological interventions for neurodevelopmental disorders is disseminated.

Bibliometric analysis is a useful tool particularly for newly emerging and rapidly developing research fields (Baminiwatta & Solangaarachchi, 2021). The purpose of the present bibliometric study was to provide an overview of the research topics and places of dissemination of studies of robots in the context of neurodevelopmental disorders. This information is essential to understanding the direction of this emerging research area. Given the specialist knowledge required to respond to the needs of individuals with neurodevelopmental disorders, it is important to highlight the extent to which such research work is connected to the psychological literature and its theoretical frameworks. Literature searches were therefore conducted to explore the research areas and topics most frequently associated with research on robots in the context of neurodevelopmental disorders but also more broadly in psychology, particularly to identify any trends.

Method

Search Strategy and Data Retrieval

Bibliographic searches were conducted using the database Scopus, which is commonly used in bibliometric studies and is known for its particularly broad coverage of journals in a wide range of fields (Archambault et al., 2009; Mongeon & Paul-Hus, 2016). A first search identified all documents that mentioned (in the article title, abstract, and keywords) both the word stem "robot" (e.g., robot and robotics) as well as one of several terms relevant to neurodiversity and neurodevelopmental disorders (Table 1). In total, data for 1763 documents were downloaded in CSV file format. A second search used the combination of the word stem "robot" as well as "psychol," which identified variations of relevant words, such as "psychology," "psychological," or "psychologist." Due to the large number of hits for this search and the intention to map out trends over time, separate searches

Table 1 Search terms used for the bibliometric analyses

Search	Search terms	Number of hits
First search	(ABS (robot*) AND ABS (schizophren* OR autism OR autistic OR "mental illness" OR adhd OR "attention deficit" OR "intellectual disability" OR neurodivers* OR neurodevelopment*))	1763
Second search (prior to 2013)	ABS (robot* AND psychol*)	1908
Second search (2013 until 2018)	ABS (robot* AND psychol*)	1817
Second search (2019 until present)	ABS (robot* AND psychol*)	1821

were conducted for different time periods (prior to 2013, 2013 until and including 2018, and 2019 until present). Each search yielded slightly less than 2000 hits (Table 1). All searches were conducted on the 21st of October, 2022.

Data Analysis and Visualization

VOSviewer (version 1.6.18) was used to analyze and visualize the bibliometric data obtained in the literature searches. VOSviewer (van Eck & Waltman, 2010) can create a variety of visualizations, such as networks of keywords that publications have in common. For each type of analysis (e.g., keyword), items are commonly found phrases and words that are then displayed as a circle with a corresponding label. The size of the circle reflects the relative importance of the item within the network. VOSviewer uses distance-based maps where the strength of the relation between items in the network is expressed in terms of distance between them, such that proximity indicates a closer relation (van Eck & Waltman, 2010). However, the relationship between items is also displayed as individual links, where the numerical value of the strength of the relationship between items (such as the co-occurrence of items) is expressed through the thickness of the visual connection. Coloring of circles is used to indicate clustering of items (van Eck & Waltman, 2010). In density visualizations, the weight (importance) of an item is indicated by the font size for the item.

When conducting keyword searches, we included both index and author keywords. For any resulting map, generic terms such as "human," "male," "female," or "research" were excluded as they provide no informational value for the bibliometric analyses. The terms "robot," "robots," and "robotics" were also excluded as these terms had already set the overall context of the publications that had been identified through their inclusion as search terms. Inclusion of these terms in the visualizations would have resulted in a trivial depiction of keyword co-occurrence. However, phrases such as "human–robot interaction" or "socially assistive robots" were included.

Results

Figure 1 shows a visualization of the co-occurrence of keywords identified in the first search (Table 1) about robots and neurodevelopmental disorders. A wide variety of keywords were found, highlighting the diversity of the studies. Research in the context of ASD was clearly predominant, even when accounting for the fact that such work had been communicated using several variations

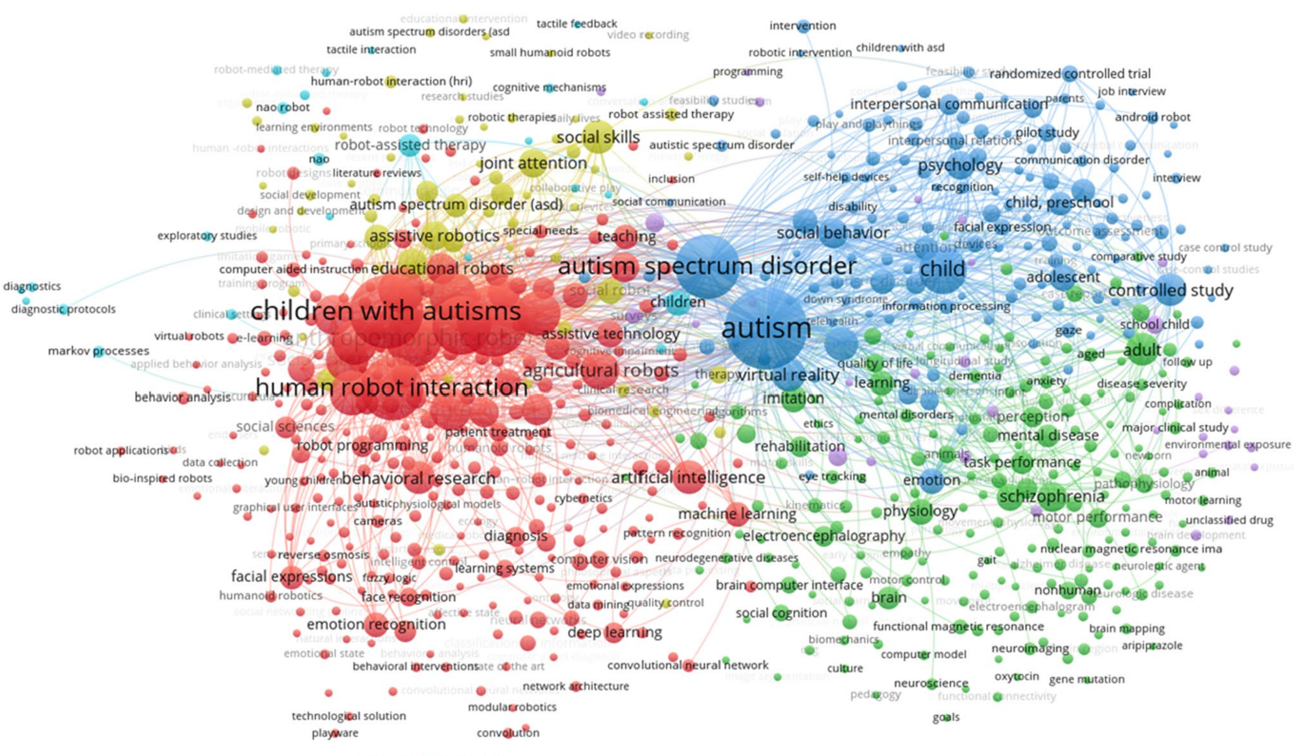

Fig. 1 Keyword network visualization for research on robots and neurodevelopmental disorders

of relevant terms and phrases. Closely associated with this were the items "social interactions," "anthropomorphic robots," and "human robot interaction," but also "educational robots," "assistive robots," and "assistive technology." The only other neurodevelopmental disorder displayed in the visualization was schizophrenia. Such work was published in different contexts, namely, those relating to neurorehabilitation, motor performance, and emotion.

Tables 2 and 3 list the most prolific and highly cited authors, respectively, within this search of research on robots and neurodevelopmental disorders. Information about affiliation was extracted from the most recent article identified in the search. For some of the authors (e.g., Kerstin Dautenhahn), their affiliation may have changed in the meantime. If an author listed more than one affiliation, the university affiliation is shown. If both affiliations were to a university, only the first one is shown. When no information was provided in the publication about either the department, school, or faculty of the author, this information was obtained through an independent search.

The most prolific author was Kerstin Dautenhahn, followed closely by Ben Robins from the same school within the University of Hertfordshire. Of the remaining authors, seven were based in Japan, three were based in Malaysia, and three in the USA. One author each was affiliated with a university in Belgium, France, the Netherlands, Portugal, and Qatar. When ranking authors in terms of citations within this search (Table 3), the first two authors were identical to Table 2, but a different representation emerged for the remaining authors in the list. There were two additional authors from the UK, taking the total from that country to five. Four authors were based in the USA, and two each in France, Japan, and Malaysia. The same authors from Belgium and Qatar were present, but there were now also authors from Romania and Switzerland.

In terms of disciplines represented in the most prolific and highly cited authors listed in Tables 2 and 3, there was a preponderance of authors from computer science and engineering. Five authors in Table 2 (Hirokazu Kumazaki, Zachary Warren, Masaru Mimura, Fazah Akhtar Hanapiah, and Taro Muramatsu) and two authors in Table 3 (Giovanni Pioggia and Frederick Shic) were affiliated with a medical school or a biomedical research institute. The only authors from a psychology department or school were Sebastian

Table 2 List of 20 most prolific authors and their affiliation, within the search of research on robots and neurodevelopmental disorders

Number of publications	Author name	Affiliation
60	Kerstin Dautenhahn	School of Computer Science, University of Hertfordshire, Hatfield, UK
50	Ben Robins	School of Computer Science, University of Hertfordshire, Hatfield, UK
37	Hanafiah Yussof	Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia
29	Nilanjan Sarkar	Department of Electrical Engineering and Computer Science/Department of Mechanical Engineering, Vanderbilt University, Nashville, TN, USA
29	Syamimi Shamsuddin	Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
28	Hirokazu Kumazaki	Department of Neuropsychiatry, Keio University School of Medicine, Tokyo, Japan
27	Hiroshi Ishiguro	Department of Systems Innovation, Graduate School of Engineering Science, Osaka University, Osaka, Japan
26	Yuichiro Yoshikawa	Department of Systems Innovation, Graduate School of Engineering Science, Osaka University, Osaka, Japan
21	Yoshio Matsumoto	College of Science and Engineering, Kanazawa University, Kanazawa, Japan
21	Zachary Warren	Treatment and Research Institute of Autism Spectrum Disorders, Vanderbilt Kennedy Center, Vanderbilt University Medical Center, Nashville, TN, USA
21	Filomena Soares	Centro Algoritmi, Campus of Azurém, University of Minho, Guimaraes, Portugal
20	Bram Vanderborght	Department of Mechanical Engineering, Faculty of Applied Sciences, Vrije Universiteit Brussel, Brussel, Belgium
20	Masaru Mimura	Department of Neuropsychiatry, Keio University School of Medicine, Tokyo, Japan
19	Tino Lourens	TiViPe, Helmond, The Netherlands
18	Fazah Akhtar Hanapiah	Faculty of Medicine, Universiti Teknologi MARA, Shah Alam, Malaysia
18	Chung Hyuk Park	Department of Biomedical Engineering, School of Engineering and Applied Science, George Washington University, Washington, DC, United States
16	Mitsuru Kikuchi	Research Center for Child Mental Development, Kanazawa University, Ishikawa, Japan
16	Taro Muramatsu	Department of Neuropsychiatry, Keio University School of Medicine, Tokyo, Japan
17	Mohamed Chetouani	Institut des Systèmes Intelligents et de Robotique, Sorbonne Université, Paris, France
17	John-John Cabibihan	Department of Mechanical and Industrial Engineering, Qatar University, Doha, Qatar

Table 3 List of 20 most highly cited authors and their affiliation, within the search of research on robots and neurodevelopmental disorders

Number of citations	Author name	Affiliation
4507	Kerstin Dautenhahn	School of Computer Science, University of Hertfordshire, Hatfield, UK
2906	Ben Robins	School of Computer Science, University of Hertfordshire, Hatfield, UK
1471	Brian Scassellati	Department of Computer Science, Yale University, New Haven, USA
915	Nilanjan Sarkar	Department of Electrical Engineering and Computer Science/Department of Mechanical Engineering, Vanderbilt University, Nashville, TN, USA
794	Aude Billard	Learning Algorithms and Systems Laboratory, School of Engineering, EPFL, Lausanne, Switzerland
792	Hideki Kozima	School of Project Design, Miyagi University, Miyagi, Japan
785	Cocoro Nakagawa	National Institute of Information and Communications Technology, Kyoto, Japan
680	Giovanni Pioggia	Institute for Biomedical Research and Innovation (IRIB), National Research Council of Italy (CNR), Messina, Italy
636	Bram Vanderborght	Department of Mechanical Engineering, Faculty of Applied Sciences, Vrije Universiteit Brussel, Brussel, Belgium
616	Iain Werry	School of Computer Science, University of Hertfordshire, Hatfield, UK
585	Hanafiah Yussof	Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia
537	Sebastian Pintea	Department of Psychology, Babeş-Bolyal University, Cluj-Napoca, Romania
521	Paul Dickerson	School of Psychology, University of Roehampton, London, UK
513	David Feil-Seifer	Department of Computer Science and Engineering, University of Nevada, Reno, Nevada, USA
507	Syamimi Shamsuddin	Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
502	Mohamed Chetouani	Institut des Systèmes Intelligents et de Robotique, Sorbonne Université, Paris, France
488	John-John Cabibihan	Department of Mechanical and Industrial Engineering, Qatar University, Doha, Qatar
484	Daniel O. David	Department of Clinical Psychology and Psychotherapy, Babeş-Bolyal University, Cluj-Napoca, Romania
480	David Cohen	Institut des Systèmes Intelligents et de Robotique, Sorbonne Université, Paris, France
468	Frederick Shic	Child Study Center, Yale School of Medicine, New Haven, USA

Pintea and Daniel O. David from Babeş-Bolyal University in Romania and Paul Dickerson from the University of Roehampton in the UK.

Table 4 presents the results from an analysis of the most frequent publication outlets, i.e., names of journals and conference proceedings. For comparative purposes, results from the four searches (Table 1) are listed side by side. For each search, results from the top seven most frequent publication outlets are shown. In cases where two outlets had the same number, both publications are shown. The cut-off of the seven most frequent outlets ensured that a sufficiently large sample was included for the purpose of illustrating where robot research in the context of neurodevelopmental disorders and in psychology tends to be published. A number larger than seven would not have served much further informative benefit.

For research on robots in the context of neurodevelopmental disorders, *Lecture Notes in Computer Science* was the most frequent publication outlet, with a frequency of 143. The frequency of the remaining six publications ranged from 26 to 48. Of these, three were conference proceedings, and one was a book series (*Advances in Intelligent Systems and Computing*). The two journals included in the list (Table 4) were *International Journal of Social Robotics* and *Journal of Autism and Developmental Disorders*.

For the three time-defined searches of robot research and psychology, *Lecture Notes in Computer Science* was also the predominant publication outlet. For the search of literature prior to 2013, *Lecture Notes in Computer Science* was the second most common outlet (just below a conference proceeding), and for the other two searches, it was on top of the list. Overall, much of the work was published as conference proceedings. From 2013, research was increasingly published in open-access journals, such as *PLoS ONE*, *Sensors*, and *Frontiers in Psychology*. Together with *International Journal of Social Robotics*, these four journals are now in top of the seven list of research outlets from 2019.

The increasing trend away from the domination of engineering and computer science in the exploration of robots in psychological context is also evident in the subsequent visualizations. The top, middle, and bottom visualizations of Fig. 2 show a network map of keyword co-occurrence across publications for the time windows pre-2013, 2013 to 2018, and post-2018, respectively. For work prior to 2013, the item "psychology" played a relatively minor role. Related items such as "psychological aspect," "psychomotor performance," and "psychotherapy" also had small weight in the network and were part of various other clusters. This is in contrast with the visualizations for research after 2013, where the item "psychology" played a more central role and was the

Table 4 Number of hits for the seven most frequent publication outlets. Results are shown separately for searches involving neurodevelopmental disorders and robots as well as psychology and robots over three different time periods. The combined list of the publications from all searches is presented in alphabetical order

Publication name	Neurodevelopmental disorders	Psychology (pre-2013)	Psychology (2013–2018)	Psychology (2019 to present)
AAAI Workshop – Technical Report		15		
ACM International Conference Proceeding Series	37			
ACM/IEEE International Conference on Human–Robot Interaction	48		60	36
Advances in Intelligent Systems and Computing	45		21	28
Connection Science		16		
Frontiers in Psychology				24
IEEE International Conference on Intelligent Robots and Systems		37		
IEEE Transactions on Neural System		16	34	
International Journal of Social Robotics	42		25	48
Journal of Autism and Developmental Disorders	26			
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*	143	74	68	53
Neural Networks		32		
PLoS ONE			36	21
Proceedings—IEEE International Conference on Robotics and Automation		43		
Proceedings—IEEE International Workshop on Robot and Human Interactive Communication	38	82	17	
Proceedings of SPIE – The International Society of Optical Engineering		15		
Sensors				38

*For brevity, henceforth abbreviated in the text to *Lecture Notes in Computer Science*

dominant item within its own cluster. The item is now linked to a wider range of items, including "cognition" and "mental health."

Discussion

The present bibliometric analysis provided an overview of the research topics in studies about robots in the context of neurodevelopmental disorders as well as psychology more broadly. Of all the neurodevelopmental disorders, ASD was by far the most frequently studied, followed by schizophrenia. The topics most closely associated with ASD and robots were assistive technologies and the teaching of social and communication skills, thus consistent with the studies reviewed by Damianidou et al. (2020). The reason for the popularity of robots in work with ASD appears to be related to the ability to provide a predictable and structured learning environment through this technology, which is particularly important for individuals with ASD (Kumazaki et al., 2020).

With the strong focus of robotics research on ASD, one may expect that many researchers have a background in the health sciences. However, our analysis of the affiliation of the most prolific and highly cited authors (within the pool of studies on robots and neurodevelopmental disorders) did not indicate that this was the case. While medical sciences were reasonably well represented, there was relatively little representation from the field of psychology. Most of the researchers in the list of top 20 most prolific and highly cited authors were associated with a university unit related to engineering or computer science. Certainly, this does not necessarily mean that this work is not sufficiently informed by an understanding of the needs of people with neurodevelopmental disorders. Many of the publications by authors on top of the lists in Tables 2 and 3 do have several authors, and some of these publications included a co-author affiliated with a psychology department (e.g., Cao et al., 2020). Nevertheless, the findings indicate that the research field is largely spearheaded by experts in the development of robotic technology rather than by researchers whose main focus is on health sciences.

The predominance of engineering in robot studies about neurodevelopmental disorders and psychology is also clearly visible in terms of the publications where this type of work is most frequently disseminated. Much of this work appears in conference proceedings for engineering and robotics conferences. A notable exception is the multidisciplinary *International Journal of Social Robotics*, which was launched in 2009 and very recently (since 2019) became the second most common outlet for work on robots in the context of

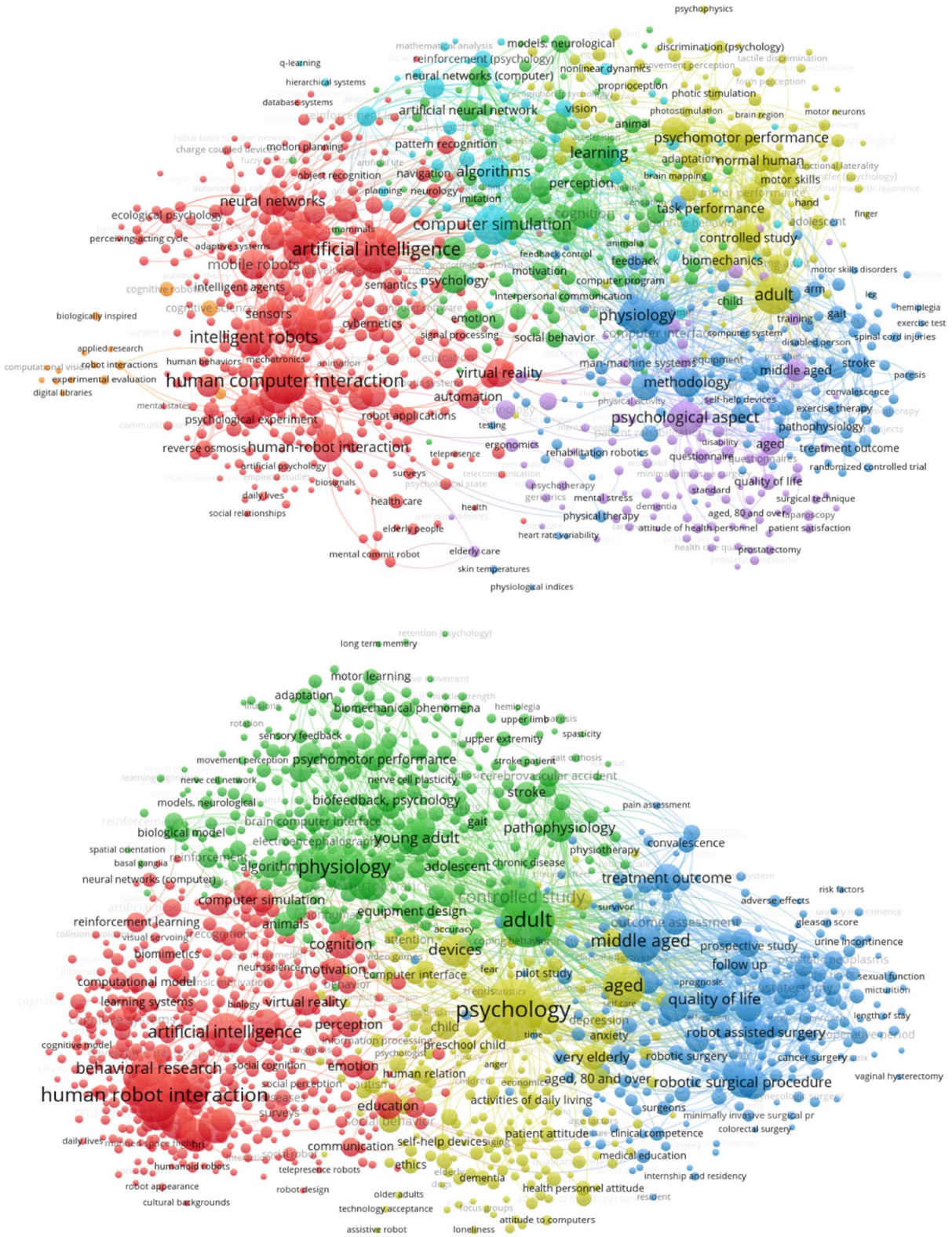

Fig. 2 Keyword network visualization for research on robots and psychology. The top visualization shows the network for studies conducted prior to 2013, the visualization in the center illustrates research occurring between (and including) 2013 and 2018, and the visualization at the bottom shows results for work published in 2019 and later

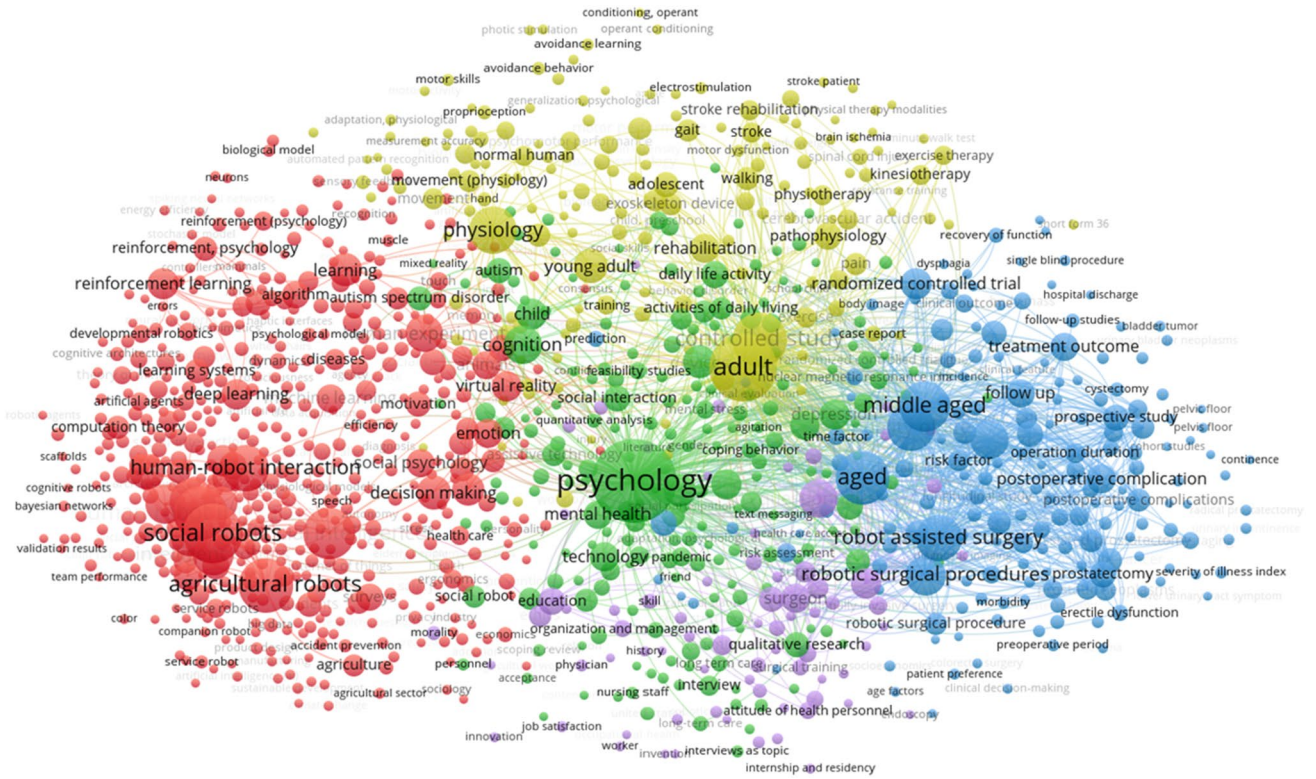

Fig. 2 (continued)

psychology. At the same time, related research has also increasingly been published in the open-access journals *PLoS ONE* and *Sensors*, where the former is very broad and multidisciplinary and the latter presents its scope as being within science and technology. For research work related to robots and psychology published during 2019 and later, *Frontiers in Psychology* has appeared as the 6th most common publication outlet, which may potentially signal an increasing role for psychology and related health discipline in this field of research.

As the visualization of keyword networks by time period (Fig. 2) shows, psychology is increasingly mentioned in robotics research. It is likely that, in future years, more publications will appear in journals that are specifically about psychology. This trend will ensure that a larger number of submissions are evaluated by editors and peer reviewers who are familiar with psychological theory and methods. Closer integration with psychological theory such as those related to attachment (Pozharliev et al., 2021), social roles (Eagly & Wood, 2012), or meaningfulness (Wong, 2013) is important as robot research continues to be applied to more complex human situations, including companionship (Broadbent, 2017), intimacy (Döring et al., 2020; Viik, 2020), and spirituality (Trovato et al., 2021). Such work will also need to be based on the best available standards for research design and measurement in psychological research. As Krägeloh et al. (2019) have outlined in their review of robot acceptability questionnaires, for example, more work is required to ensure relevant questionnaires meet adequate psychometric standards.

As the present bibliometric review illustrated, psychology researchers increasingly appear to contribute to studies about the application of robots in psychosocial situations. However, as the present review has also highlighted, such work continues to be largely confined to publications related to science, engineering, and technology or to journals that are either multidisciplinary or about general psychology. Without the existence of a specialist publication outlet, the development of the application of psychological theory in robotics will likely continue in an unsystematic and suboptimal fashion. Krägeloh et al. (2022) have recently called for the launch of the sub-discipline of robopsychology to meet the demands for a scientific infrastructure for work about the psychological implications of robotics. Appropriate first steps in this direction would be the establishment of a professional association and an academic journal dedicated to the topic of robopsychology.

The recognized benefits of gathering expertise within specific sub-disciplines have undoubtedly led to the diverse landscape of sub-disciplines in psychology. In the case of robopsychology, the transformative potential of new technologies is inherent in its definition as "the psychology of,

for, and by robots, robotics, and artificial intelligence (AI)" (Krägeloh et al., 2022, p. 6). As robotics and AI continue to grow in sophistication, the extent of their impact on psychology and the field of research on neurodevelopmental disorders will have a steep growth trajectory.

Limitations and Future Research Directions

The present bibliometric analysis identified 7309 publications across its four searches, with no attempt to peruse every single one of them to verify that the hits were directly relevant to the research question. However, the restriction to include the search terms only within either the title, abstract, or keywords was implemented to ensure that these terms were not just mentioned in the periphery. A random inspection of a sample of hits confirmed that the search did indeed identify publications as intended. As frequently described in this article, the searches were assumed to have identified research that had occurred *in the context of neurodevelopmental disorders* or *in the context of psychology*. Future reviews are required to explore to what extent the present bibliometric findings also apply to more restricted search terms, such as specific intervention types, research designs, or sub-topics around neurodevelopmental disorders or within the field of psychology. Such work may also benefit from the use of a different type of bibliometric analysis software to minimize any bias that may have occurred from the choice of Scopus and VOSviewer (Mongeon & Paul-Hus, 2016).

While the analyses of the top prolific and highly cited authors clearly indicated that authors from psychology and related health disciplines are not strongly represented, more detailed analyses are needed to highlight their overall participation. A search through the most recent work of the authors on top of the list does reveal that these publications tend to be co-authored with other researchers from engineering and computer science. In contrast, other research groups (e.g., such as those associated with Bram Vanderborght) appear to draw on a wider range of expertise within the author team for their articles, such as by including psychology researchers (Cao et al., 2020). Further bibliometric work could explore whether such work is more likely to investigate psychological topics and to what extent it may have an increased tendency to draw on psychological theories and models.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41252-023-00318-5.

Acknowledgements We thank Dr. J. Sundeep Anand, President, Bharath Institute of Higher Education and Research for his support during the study.

Author Contribution Chris Krägeloh: conceptualization, data curation, formal analysis, funding acquisition, methodology, software, and writing—original draft. Jaishankar Bharatharaj: conceptualization, funding acquisition, and writing—review and editing. Marcel Heerink: conceptualization and writing—review and editing. Daniel Hannon: conceptualization, funding acquisition, and writing—review and editing. Jordi Albo-Canals: conceptualization and writing—review and editing.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. This research was funded by matching grant funding by Auckland University of Technology and Bharath Institute of Higher Education and Research for the establishment of the Psychosocial Aspects in Robotics (PAIR) Lab.

Data Availability The datasets analyzed during the current study are available as a file in Supplementary Online Material.

Declarations

Ethics Approval The present study used already published material, and no ethics approval was required.

Informed Consent The present study used already published material involving no participants.

Conflict of Interest Jordi Albo-Canals was employed by the company Lighthouse Disruptive Innovation Group, LLC. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Archambault, É., Campbell, D., Gingras, Y., & Larivière, V. (2009). Comparing bibliometric statistics obtained from the Web of Science and Scopus. *Journal of the American Society for Information Science and Technology, 60*(7), 1320–1326. https://doi.org/10.1002/asi.21062

Arulkirubakaran, D., Malkiya Rasalin Prince, R., Nagarajesh, T. C. S., Palanisamy, D., Anand, K. N., Siddharth, S., Nagasuresh, M., Kishore, K. CH. S., & Abhishek, N. S. (2022). Evolution of industrial robots during mid of nineteenth century–beginning of twentieth century—A review. In I. A. Palani, P. Sathiya, & D. Palanisamy (Eds.), *Recent advances in materials and modern manufacturing* (pp. 143–154). Springer. https://doi.org/10.1007/978-981-19-0244-4_15

Baminiwatta, A., & Solangaarachchi, I. (2021). Trends and developments in mindfulness research over 55 years: A bibliometric analysis of publications indexed in web of science. *Mindfulness, 12*(9), 2099–2116. https://doi.org/10.1007/s12671-021-01681-x

Bartneck, C., & Forlizzi, J. (2004). A design-centred framework for social human-robot interaction. In *RO-MAN 2004: 13th IEEE International Workshop on Robot and Human Interactive Communication, September 20–22, 2004, Kurashiki* (pp. 591–594). Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/ROMAN.2004.1374827

Broadbent, E. (2017). Interactions with robots: The truths we reveal about ourselves. *Annual Review of Psychology, 68*(1), 627–652. https://doi.org/10.1146/annurev-psych-010416-043958

Cao, H. L., Simut, R. E., Desmet, N., De Beir, A., Van De Perre, G., Vanderborght, B., & Vanderfaeillie, J. (2020). Robot-assisted joint attention: A comparative study between children with autism spectrum disorder and typically developing children in interaction with NAO. *IEEE Access, 8*, 223325–223334. https://doi.org/10.1109/ACCESS.2020.3044483

Cepolina, F., & Razzoli, R. P. (2022). An introductory review of robotically assisted surgical systems. *International Journal of Medical Robotics and Computer Assisted Surgery*, *18*(4), e2409. https://doi.org/10.1002/rcs.2409

Chu, S. T., Hwang, G. J., & Tu, Y. F. (2022). Artificial intelligence-based robots in education: A systematic review of selected SSCI publications. *Computers and Education: Artificial Intelligence*, *3*, 100091. https://doi.org/10.1016/j.caeai.2022.100091

Cowley, S. J., & Gahrns-Andersen, R. (2022). Drones, robots and perceived autonomy: Implications for living human beings. *AI & Society, 37*(2), 591–594. https://doi.org/10.1007/s00146-020-01133-5

Damianidou, D., Eidels, A., & Arthur-Kelly, M. (2020). The use of robots in social communications and interactions for individuals with ASD: A systematic review. *Advances in Neurodevelopmental Disorders, 4*(4), 357–388. https://doi.org/10.1007/s41252-020-00184-5

Döring, N., Mohseni, M. R., & Walter, R. (2020). Design, use, and effects of sex dolls and sex robots: Scoping review. *Journal of Medical Internet Research*, *22*(7), e18551. https://doi.org/10.2196/18551

Eagly, A. H., & Wood, W. (2012). Social role theory. In P. A. M. Van Lange, E. T. Higgins, & A. W. Kruglanski (Eds.), *Handbook of theories of social psychology* (pp. 458–476). Sage Publication.

Guemghar, I., de Oliveira Padilha, P. P., Abdel-Baki, A., Jutras-Aswad, D., Paquette, J., & Pomey, M. P. (2022). Social robot interventions in mental health care and their outcomes, barriers, and facilitators: Scoping review. *JMIR Mental Health*, *9*(4), e36094. https://doi.org/10.2196/36094

Krägeloh, C. U., Bharatharaj, J., Kutty, S. K. S., Nirmala, P. R., & Huang, L. (2019). Questionnaires to measure acceptability of social robots: A critical review. *Robotics, 8*(4), 88. https://doi.org/10.3390/robotics8040088

Krägeloh, C. U., Bharatharaj, J., Albo-Canals, J., Hannon, D., & Heerink, M. (2022). The time is ripe for robopsychology. *Frontiers in Psychology*, *13*, 968382. https://doi.org/10.3389/fpsyg.2022.968382

Kumazaki, H., Muramatsu, T., Yoshikawa, Y., Matsumoto, Y., Ishiguro, H., Kikuchi, M., Sumiyoshi, T., & Mimura, M. (2020). Optimal robot for intervention for individuals with autism spectrum disorders. *Psychiatry and Clinical Neurosciences, 74*(11), 581–586. https://doi.org/10.1111/pcn.13132/full

Marcos-Pablos, S., & García-Peñalvo, F. J. (2022). More than surgical tools: A systematic review of robots as didactic tools for the education of professionals in health sciences. *Advances in Health Sciences Education*. https://doi.org/10.1007/s10459-022-10118-6

Mejia, C., & Kajikawa, Y. (2017). Bibliometric analysis of social robotics research: Identifying research trends and knowledgebase. *Applied Sciences, 7*(12), 1316. https://doi.org/10.3390/app7121316

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics, 106*(1), 213–228. https://doi.org/10.1007/s11192-015-1765-5

Pozharliev, R., De Angelis, M., Rossi, D., Romani, S., Verbeke, W., & Cherubino, P. (2021). Attachment styles moderate customer responses to frontline service robots: Evidence from affective, attitudinal, and behavioral measures. *Psychology & Marketing, 38*(5), 881–895. https://doi.org/10.1002/mar.21475

Pratticò, F. G., & Lamberti, F. (2020). Mixed-reality robotic games: Design guidelines for effective entertainment with consumer robots. *IEEE Consumer Electronics Magazine, 10*(1), 6–16. https://doi.org/10.1109/MCE.2020.2988578

Robinson, H., MacDonald, B., Kerse, N., & Broadbent, E. (2013). The psychosocial effects of a companion robot: A randomized controlled trial. *Journal of the American Medical Directors Association, 14*(9), 661–667. https://doi.org/10.1016/j.jamda.2013.02.007

Rosete, A., Soares, B., Salvadorinho, J., Reis, J., & Amorim, M. (2020). Service robots in the hospitality industry: An exploratory literature review. In H. Nóvoa, M. Drăgoicea, & N. Kühl (Eds.), *International conference on exploring services science* (pp. 174–186). Springer.

So, W.-C., Wong, M.K.-Y., Lam, W.-Y., Cheng, C.-H., Ku, S.-Y., Lam, K.-Y., Huang, Y., & Wong, W.-L. (2019). Who is a better teacher for children with autism? Comparison of learning outcomes between robot-based and human-based interventions in gestural production and recognition. *Research in Developmental Disabilities, 86*, 62–75. https://doi.org/10.1016/j.ridd.2019.01.002

Trovato, G., De Saint Chamas, L., Nishimura, M., Paredes, R., Lucho, C., Huerta-Mercado, A., & Cuellar, F. (2021). Religion and robots: Towards the synthesis of two extremes. *International Journal of Social Robotics, 13*(4), 539–556. https://doi.org/10.1007/s12369-019-00553-8

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Viik, T. (2020). Falling in love with robots: A phenomenological study of experiencing technological alterities. *Paladyn, Journal of Behavioral Robotics, 11*(1), 52–65. https://doi.org/10.1515/pjbr-2020-0005

Wada, K., Shibata, T., & Kawaguchi Y (2009). Long-term robot therapy in a health service facility for the aged-A case study for 5 years. In *2009 IEEE International Conference on Rehabilitation Robotics* (pp. 930–933). Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/ICORR.2009.5209495

Wong, P. T. (2013). *The human quest for meaning: Theories, research, and applications*. Routledge.