



## THE NETWORK SCIENCE APPROACH IN DETERMINING THE INTELLECTUAL STRUCTURE, EMERGING TRENDS AND FUTURE RESEARCH OPPORTUNITIES: AN APPLICATION TO TAI CHI FOR OLDER ADULTS

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**Abstract:** This article focuses on the geriatric market segment which is becoming increasingly important as a result of demographic trends and aging populations. Using network science approach, this study maps the structure of knowledge, its changes over time and research opportunities in Tai-chi. Data collected from Web-of-Science and Scopus between 1996-2019 was used to build a network of 2,202 articles and 6,820 authors. The results show Tai-chi represents a small-world network as the majority of the articles were produced among universities and medical schools, displaying a connection between theoretical knowledge and pragmatic applications. The scientific achievements mainly emerge from the USA, China, and UK. The collaborative efforts focused on a giant component and converge on a small area of research. Future opportunities at the intersection of Tai-chi and geriatrics include mindfulness-meditation, osteoarthritis, sleep quality, cardio-respiratory function and pain management. This article provides contributes to the literature on Tai-chi and offers insights into the capabilities of CiteSpace, Vosviewer, Gephi, and Python.

**Keywords:** Tai-chi, older adults, network science approach, intellectual structure, emerging trends.

### 1. INTRODUCTION

The progressive aging of the population and increased life expectancy demand strategies to improve the quality of life for older adults. Tai-chi has attracted several researchers for whom this field has a role in promoting health for this important segment (Behere et al., 2019; Lan et al., 2013; Gillespie et al., 2012). It is therefore important to understand how knowledge acquisition and information dissemination occurred in the subject field of Tai-chi for older adults.

Tai-chi is an effective body-mind exercise program that benefits and promotes health (Behere et al., 2019), including physical and mental activity, psychological well-being (Blake

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& Hawley, 2012), and a better quality of life (Lan et al., 2013). The multifaceted characteristics of Tai-chi can enhance balance and confidence of older adults (Blake & Hawley, 2012), strengthen muscles (Lan et al., 2013), and prevent falls (Gillespie et al., 2012). In fact, injuries resulting from falls are the cause of more than half of hospital admissions for older adults (El-Khoury et al., 2013; Wayne, et al., 2011). It is also documented that Tai-chi can enhance cognition and brain health in older adults (Chang et al., 2014). For example, Tai-chi has positive effects in people with Parkinson's disease (Lee et al., 2008; Amano et al., 2013), depression (Liu et al., 2019), and sleep problems (Si et al., 2019). In addition to its brain benefits, Tai-chi research has touched the fields of rheumatology (Wang, 2012), chronic pain (Peng, 2012), osteoporosis and cancer (Drake, 2013), cardiovascular disease (Pan, 2016), and cardiopulmonary function (Sun et al., 2019), and therefore can have positive effects on older adults' health.

The complexity of scientific research of Tai-chi as geriatric therapy required a network science approach. Most studies on Tai-chi are descriptive and cross-sectional, and just a very few include a bibliometric analysis. Consequently, in-depth bibliometric studies are needed for Tai-chi. In the current study, the collaborative network was analyzed from 1996 until 2019 through the perspective of social network analysis (SNA), whereby authors and areas of research are represented as nodes, and their inter-relationships present as edges in a graph which employs several centrality metrics. Data were collected from Web-of-Science (WoS) and Scopus, considered the most widespread and best quality databases for literature searches in different scientific fields (Guz & Rushchitsky, 2009). The objectives of this study were: (i) to analyze whether or not Tai-chi is evolving as a collaborative network; (ii) to determine whether or not Tai-chi is similar to most SNA as small-world, identified by a giant component of interconnected authors, allowing the information to be easily accessed and updated; (iii) to evaluate and identify critical researchers using centrality metrics (iv) to analyze the occurrence of a positive association between authors' centrality metrics and their productivity and degree of collaboration; (v) to know the institutions and countries from where the knowledge derives; (vi) to determine the presence of an internal cohesion among the research topics and to identify the hot spots and research opportunities.

## 2. METHODS

In this paper, we analyze a community structure by examining not only modularity but also the following attributes of the network: density, average clustering coefficient, average path length, and diameter. At micro level we assessed the performance of both networks adding the following centrality measures: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. Various free Java software tools were used in our research to proceed with our SNA analysis: CiteSpace(<http://cluster.cis.drexel.edu/~cchen/citespace>), was used to convert Scopus data in WoS data and to obtain bursts of keywords used to identify research opportunities; Vosviewer (<https://www.vosviewer.com/>), was used as input to create files of nodes and edges needed to be analyzed and visualized through Gephi (<https://gephi.org/>). Gephi was used to measure both co-authorship networks and co-occurring keyword network networks, using centrality metrics; and Python (<https://www.python.org/downloads/windows/>), was used to clean the data, to eliminate duplicates and synonyms, and to obtain the files by authors, institutions, countries and keywords. The harmonization or disambiguation of institutions, author names and country names are key to attribute articles to their correct authors, institutions, and countries.

The current research focuses on a longitudinal data set from January 1996 to December 2019 with the aim of studying the evolutionary dynamics of scientific collaboration networks

and Tai-chi research areas. Data were collected from Web-of-Sciences (WoS) and Scopus. The dimensions chosen as a basis for selecting the documents were keywords, English language, and years of publication. To obtain more scientific and accurate data, only the following keywords included in the title, abstract or keywords were extracted (Fu et al., 2012): “Tai-chi” OR “tai-chi” OR “t'ai chi” OR “tai ji” OR “tai-ji” OR “Tai-chi chuan” OR “taijiquan” OR “tai ji quan” OR “shadow boxing.” OR “aging” OR “Older” OR “senior”. Among the published documents, the analysis relates only to articles considered to be responsible for the advancements within and among disciplines (Pestana & Sobral, 2019).

### 3. RESULTS

After merging synonyms and eliminating duplicates records, we obtained a net sample of 2,202 articles, reflecting the contribution of 6,820 authors with 28,855 collaborations (links), from 3,215 institutes in 61 countries. Research in Tai-chi for older adults is essentially approached through co-authorship (86.4%). There are 296 single articles, and 262 isolated authors. On average there are 4.4 authors per article, with emphasis on 32.2% of articles made by three and four authors. The distribution of articles per author indicates a large co-authorship participation in Tai-chi research. The cohesiveness of Tai-chi collaboration network is analysed on one hand by the attributes of a node (degree, average path coefficients, averaged clustering coefficients), and on another hand by the study of Tai-chi components. Results show that the average distance between two authors across the network is 4.8, which means that information only needs to flow using four or five intermediaries to be transferred from one author to another. The high average clustering coefficient 0.813, suggests a highly clustered network with close relationships between researchers.

In the study of the collaborative network, we eliminated from the analysis isolated authors and those with few connections. These peripheral authors, with no connections or just with a single link to the entire network, could distort the understanding of our collaborative network through weak or widely dispersed nodes (Pestana, Wang, & Parreira, 2020). This pruning procedure resulted in a more simplified co-authoring network decreasing from 6,820 authors to 2,206 authors who have the highest link strength. The used of metrics shows Tai-chi network with 205 components, with a giant component containing 1,336 authors and representing 60.56% of the whole pruned network. Of the remaining 204 small components, the largest one has 18 authors. Most small components have only two, three or four authors.

Tai-chi is a small-world network, where most nodes have relative low degree collaboration, with very few having a high degree collaboration (Barabási & Alber, 1999). The spread and dissemination of Tai-chi information is therefore an easy process, where researchers can be easily updated on the progress of Tai-chi research to improve health or prevent health problems for older adults.

Figure 1 visualize the distributions of countries of the pruned network, where most connections are located at the center. The size of the characters displays the countries with the highest degree, where the China, USA, and United Kingdom stands out. The connections among countries show the international nature of Tai-chi research. Collaboration between different countries in research is likely to result in a further increase in knowledge, which may have a positive impact on the prevention of health problems among the older adults.



Figure 1. Author’s country in Tai chi (1996-2019) Source: The authors.

The authors’ Institutions of the pruned network has low density (0.01) and good modularity (0.515), being distributed among 268 institutions (nodes) with 1,237 connections (edges). The most productive institutions in the number the articles include the *Chinese University Hong Kong* and *Hong Kong Polytech University*, both in Hong Kong, with 87 and 64 publications (link strength), respectively. The United States boasts the highest number of institutions (68.4%), showing that it is a big attraction for researchers. The *Harvard Medical School* (USA) has the highest number of inter-institutional research collaborations (59 links), and co-authorship publications (link strength of 54). The *University of Sidney* (Australia) ranks 4th both in inter-institutional research collaborations (34 links) and in co-authorship publications (link strength of 59). The participation of universities and medical schools shows the relevant role of Tai-chi in treating older adult’s health, not only from the theoretical basis (universities) but also from its practical application (medical schools). Table 1 displays the top institutions distributed according to co-authorship collaboration (link strength). The number of links and their strength suggest a high collaboration among institutions, with the USA playing the greatest role.

Table 1. Author’s Institutions (1996-2019)

Top Co-authorship Institutions	Link		
	Number	Strength	Country
Chinese Univ Hong Kong	35	87	Hong Kong
Hong Kong Polytech Univ	25	64	Hong Kong
Harvard Univ	39	63	USA
Univ Sydney	34	59	Australia
Harvard Med Sch	59	54	USA
Univ Calif Los Angeles	28	48	USA
Shanghai Univ Sport	36	47	China
Univ Illinois	27	39	USA
Tufts Univ	16	38	USA
Univ Hong Kong	15	35	Hong Kong
Emory Univ	13	33	USA
Massachusetts Gen Hosp	22	31	USA
Oregon Res Inst	9	31	USA
Brigham & Women's Hosp	26	30	USA
Osher Center for Integrative Medicine	23	28	USA

Univ Arizona	10	27	USA
Univ New South Wales	19	27	Australia
Beth Israel Deaconess Med Ctr	11	25	USA
Texas Tech Univ	7	24	USA

Source: The authors.

The development of Tai-chi research is analyzed by dividing the time period into four sub-periods of six years: 1996-2001; 2002-2007, 2008-2013, 2014-2019. Over time, there is a general increase in publications, authors and collaborations, although at different rates. Growth has been slower in the number of publications, ranging from 80 in the first six years to 1036, in the last six years. The number of authors increases 7.6 times from 392 during 1996-2001 to 2,969 in the last period, while the number of links shows the greatest increase, around 17 times more, from 857 in the initial period to 15,336 in the latest period, supporting an increase over time in collaborations among authors. The average number of links per author increases slightly from 2.19 to 2.34, while in the last two subperiods they double their values, going from 4.76 to 5.17. The small number of articles by a single author (296 or 13.4%) and isolated authors (262 or 3.84%), indicates that most researchers cooperate with others. In Tai-chi, the collaboration rate has a clear upward trend especially after 2008, when the greatest progression occurs. Excluding the isolated authors, we obtain a small mean article per author (0.29) and a high mean author per article (3.58), which reflect the multidisciplinary nature of a discipline (Ye et al., 2013). Therefore, researchers from different areas seek to cooperate with specialists in Tai-chi, enriching the study by including different perspectives of scientific approach, with positive effects on disease prevention in older adults. Table 2 represent the collaborative network of Tai-chi in each of the four subperiods, to obtain a more stable analysis of the effects over time.

Table 2. The collaborative network by time periods

Year	1996- 2001	2002- 2007	2008- 2013	2014- 2019
<b>New:</b>				
Publications	80	357	729	1036
Authors	392	1574	1885	2969
Links	857	3687	8975	15336
Avg.Links/Author	2.19	2.34	4.76	5.17
<b>Cumulative:</b>				
Publications	80	437	1166	2202
Authors	392	1966	3851	6820
Links	857	4544	13519	28855
Avg.Links/Author	2.19	2.31	3.51	4.2

Source: The authors.

According to Braun, Glanzel, and Scgubert (2001), larger teams are more effective than solitary researchers. In fact, within the giant component, most critical authors are spread over 7 larger communities each one with more than 10 authors. The data show that the characteristics of these communities: modularity (0.609) is superior to 0.30 (Chen et al., 2014; Newman, 2006); diameter is not superior to 6; density and average cluster coefficient are above the homologous metrics observed in the network (Savié et al., 2014), and there is a small, averaged path length in each community (Cheong, et al, 2009). The larger community has the number 1 with 31

authors. The relevance of the degree of centrality in the study of collaborative networks is explained by the fact that this metric indicates the total number of collaborators of a researcher, thus allowing us to assess the extent of their collaborations. Researchers with more collaborators are more popular and influential in the academic community, assuming more responsibility in the transmission of information. All critical authors have low values of closeness centrality, reflecting their independence and efficiency in communicating with other authors. Concerning betweenness centrality, it identifies authors that are on the shortest path between many pair of authors, occupying a critical place in the network. Frequently, the path through a node with high betweenness centrality is the most efficient path for the control of the information. The table 3 shows twenty critical authors identified by their productivity and centrality measures. These authors produce 643 articles, which correspond to 33.7% of the total publications and collaborate with high scored authors. For example, Zhang Yan, from Beijing University of Chinese Medicine (China), collaborates with 34 researchers. Liu Jian-Ping, from Beijing University of Chinese Medicine (China), collaborates with 31 authors. Both authors can reflect the strength of their research collaboration with other authors from different countries, mainly China and USA, suggesting the internationalization role of Tai-chi research. Wayne Peter M., from Harvard Medical School (USA), is the most productive Tai-chi author, and has a quick effect on transmitting Tai-chi information across the group and on controlling the dissemination of information. Wolf Steven L. from Emory University (USA), is the most cited author and the author with the most influence over the control and spread of information anywhere in the network.

**Table 3.** Productivity and centrality of some top 20 researchers

Authors	Community	Productivity	Citations	Degree centrality	Betweenness centrality	Eigenvector centrality
Wayne, PM	1	72	1,200	25	0.503	0.999
Wang, Chenchen	2	56	1,068	21	0.238	0.499
Li, FZ	2	51	1,632	13	0.349	0.525
Yeh, GY	3	45	263	18	0.501	0.913
Tsang, WWN	4	42	727	14	0.631	0.998
Zhang, Y	5	37	328	34	0.323	0.931
Zou, L	5	35	257	22	0.154	0.929
Lee, MS	6	35	666	9	0.188	0.155
Wolf, SL	2	27	2,797	12	0.833	0.515
Yeung, AS	2	26	162	26	0.217	0.879
Liu, Y	7	26	195	23	0.372	0.656
Li, L	4	26	211	16	0.151	0.611
Taylor-Piliae	5	26	212	7	0.129	0.306
Wang, Y	2	24	144	9	0.169	0.378
Liu, J	7	23	213	31	0.355	0.987
Wang, L	6	22	119	19	0.341	0.704
Woo, J	2	22	467	5	0.122	0.219
Song, R	5	19	429	9	0.193	0.293
Lam, P	5	19	649	7	0.186	0.122
Sherrington, Catherine	5	10	1,472	5	0.356	0.245

Source: The authors.

The results show a positive and statistically significant association between the authors' centrality attributes, using Spearman's Rho. Authors with higher degree of collaborations are more independents (0.716,  $p = 0.01$ ), have a high eigenvector centrality meaning high quality of contacts (0.704,  $p = 0.01$ ), and a moderate betweenness centrality, with a moderate role in connecting different groups of researchers (0.583,  $p = 0.01$ ). There is a significant negative correlation between year of publication and number of citations ( -0.309,  $p = 0.01$ ), suggesting that, on average, the greater the number of citations received for an article, the older is the article. This result is expected as these articles will have more time to be cited than the most recent ones. Although it is observed that most productive authors have a greater number of collaborations, this relationship is not statistically relevant in Tai-chi (0.214,  $p = 0.11$ ).

The network has 2,955 keywords and is analyzed in four sub-periods in order to identify more stable variations in the evolution of themes. Top topics and areas of research are analyzed among 103 keywords with 10 or more co-occurrences. This network shows a clear representative interconnected keyword per slice, with many of its links dispersed around a few nodes (Table 4). All keywords are highly connected, as can be seen by the highest values of average clustering coefficients, as well as by the small number of intermediary's keywords between any two nodes. The average degree centrality is increasing over time; therefore, it is possible to identify the expansion of the core keywords. The density is high in all time periods, where a small group of core keywords dominates. In fact, there are 23.8% of keywords with three or more co-occurrences, suggesting that research on Tai-chi focused on a small area.

The selection of the most frequent keywords led us to identify the scientific production with greatest scientific impact, representing the mainstream of Tai-chi research in each sub-period and their evolution.

Table 4. Keywords network structure

Year	Keywords N	Keywords Links	Avg. degree	Density	Avg. clustering coefficient	Avg. path length
1996-2001	11	49	8.91	0.89	0.92	1.11
2002-2007	34	427	25.12	0.76	0.85	1.24
2008-2013	58	1351	46.59	0.82	0.89	1.18
2014-2019	59	1492	50.58	0.87	0.91	1.12

Source: The authors.

Figure 2 shows the top keywords by degree in each of the four sub-periods of time, represented by the increasing size of the characters. From 1996 until 2001 the literature is dominated by the smallest number of 11 central keywords with 49 connections (links); increasing successively to 34 central keywords with 427 connections from 2002 until 2007; to 58 central keywords with 1351 connections from 2008-2012, until 59 central keywords with 1492 connections in the last period.

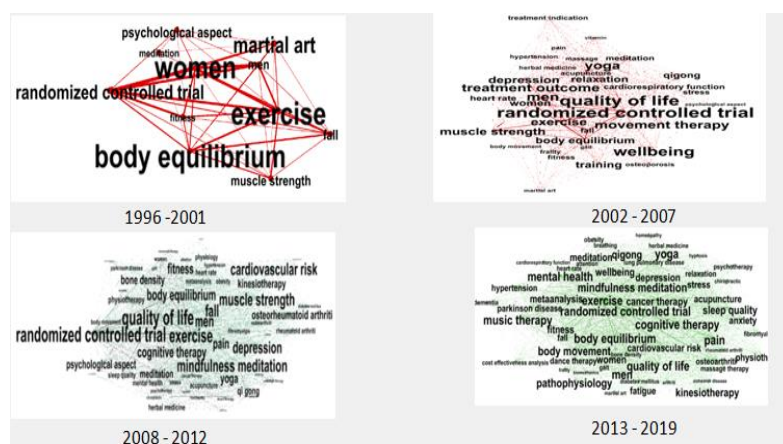


Figure 2. Keywords by degree centrality: top (1996-2001), second (2002-2007), third (2008-2012), bottom (2013-2019)

Source: The authors.

Exercise, fall, body equilibrium and internal validation through randomized controlled trials are considered important topic in all sub-periods. The last one is needed to ensure the scientific rigor of studies on intervention (Steckler & McLeroy, 2008). In the second sub-period, new topics emerge, such as quality of life, wellbeing, yoga, movement therapy, depression, relaxation, pain. After 2018 occurs the greatest amount of research and therefore new topics emerge. From 2018 until 2012 the new topics include, among others, cardiovascular risk, meta-analysis, cognitive therapy, osteoarthritis, kinesiotherapy, bone density, rheumatoid arthritis, Parkinson’s disease, mental health, and music therapy. In the last sub-period, new central topics emerged: pathophysiology, fatigue, anxiety, cost effectiveness analysis, breathing, attention, and Alzheimer’s disease. The research topics can be grouped mainly into four main areas of investigation: physical function; bones and muscles; emotional and cognitive function and internal validity. Essentially from 2018 onwards, the application of Tai-chi includes broader fields of medicine, like medical emergencies, medical rehabilitation, nervous system diseases and several different organic diseases, such as cancer, obstructive pulmonary disease and cardiovascular disease.

Through Citespace, focusing on the last period, we observed that the most recent and hot topics of research, that are attracting an extraordinary degree of attention from researchers (high burst strength), connect the Tai-chi program with the reduction or prevention of risk factors like pain, cardiorespiratory function, cancer therapy, osteoarthritis. Other hot sub-topics of Tai-chi are sleep quality and mindfulness-meditation exercises (Table 5).

Table 5. Hot spots in tai-chi research

Keywords	Strength	Begin	End	2014 - 2019
pain	16 709	<b>2014</b>	2019	
cardio respiratory function	26.57	<b>2015</b>	2019	
cancer therapy	66 255	<b>2016</b>	2019	
mindfulness-meditation	196 256	<b>2017</b>	2019	
osteoarthriti	177 401	<b>2017</b>	2019	
sleep quality	88 798	<b>2017</b>	2019	

Source: The authors.



#### 4. DISCUSSION AND CONCLUSION

Data were extracted from two high quality databases to model the collaborative author's network and co-occurring keyword network over the period 1996-2019. We show that Tai-chi is a small world network, evolving over time mainly after 2008, as a result of new researchers with new ideas have entered in this field. These results are in line with other studies also demonstrate that SNA are small worlds (Barabási & Albert, 1999). Most articles were produced among universities and medical schools, displaying a connection between theoretical knowledge and pragmatic applications. The large set of Tai-chi collaboration indicate not only its multidisciplinary nature, but also the high globalization of its research. The scientific achievements mainly come from the USA, China, and the UK. The most productive institutions are in China, while the USA has the highest number of inter-institutional research collaborations. Several metrics were used to identify the structure of both networks (authors and keywords), making the results more credible. We show the existence of a high association between the attributes of influential authors, indicating the maturity of the network structure with close relationships between researchers, which are in line with Bibi et al. (2018). There is a positive correlation between productivity and degree of collaboration, a trend which aligns with other studies (Ye et al., 2013). All critical authors have received a great number of citations showing their power in providing links between people, ideas, publications, and institutions (Blázquez-Ruiz et al., 2016). Although Tai-chi has demonstrated a high level of collaboration between authors, critical authors can play an important role in strengthening the existing collaborative network, creating connections with peripheral authors or with other isolated authors. Considering the authors' research areas, we see a convergence in Tai-chi studies focused on disease prevention. Future opportunities for older adults are mainly mindfulness-meditation, osteoarthritis, sleep quality, cardio-respiratory function, pain and external validation, this one needed to substantiate the theoretical and medical research. The most frequent keywords and those with citation bursts identify important research topics to be included in new publications. According to Sarigöl et al (2014), the topics thus created will have a high probability of relevance and, by attracting the attention of researchers, can generate many citations in the future. The relevance of our study extends past bibliometrics because we combine collaborative analysis with co-occurring keyword network to understand the development of this field from different perspectives. The complexity of the research created the need for a SNA analyses and its visualization, which was performed at micro and macro level. The application of SNA for both collaboration between authors and for research topics is innovative for the subject of Tai-chi. Nevertheless, like most studies, our own presents some limitations. In fact, the analysis is based on articles extracted from WoS and Scopus, and only includes those written in English. Therefore, it may exclude relevant authors who have published in other languages and data sets. Nevertheless, the results of our study provide new theoretical bases for future research in this field by combining four different software tools through SNA to obtain deeper insights about the collaborative network. This study intends to provide a unique understanding about the collaborative Tai-chi network as demonstrated by centrality metrics to be a knowledge domain allowing information to be easily accessed and updated; Tai-chi itself is a useful tool to all researchers interested in improving the health or preventing diseases in older adults. Centrality metrics and network metrics used in SNA and in the keyword network, can capture the social aspects that support and transmit Tai-chi-related scientific ideas, allowing stakeholders to map the intellectual structure of Tai-chi and its changes over time. In a dynamic world, a network science approach analysis should be done regularly to keep pace with research changes. Tai-chi by involving physical movement, controlled breathing and meditation helps to maintain emotional regulation and to be aware of ourselves, necessary for a healthy mind.

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