



Research article

Public perception on 'healthy ageing' in the past decade: An unsupervised machine learning of 63,809 Twitter posts

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ARTICLE INFO

Keywords:

Healthy ageing
Ageism
Public perception
Topic modelling
BERT

ABSTRACT

The World Health Organization (WHO) started the initiative on healthy ageing from 2016 to 2020, which has now continued into the United Nations (UN) Decade of Healthy Ageing 2021–2030. Research into healthy ageing and healthy ageing communities have emphasized that the concept of healthy ageing encompasses a plurality of views and has multiple dimensions. Anchored in a transdisciplinary approach, the present report thus aimed to investigate public perceptions of healthy ageing via a deep analysis of social media posts on Twitter. Original tweets, containing the terms “Healthy Ageing” OR “healthy aging” OR “healthyageing” OR “healthyaging”, and posted in English between 1 January 2012 and 30 June 2022 were extracted. Bidirectional Encoder Representations from Transformers (BERT) Named Entity Recognition was applied to select for individual users. Topic modelling, specifically BERTopic was used to generate interpretable topics and descriptions pertaining to the concept of healthy ageing. Subsequently, manual thematic analysis was performed by the study investigators, with independent reviews of the topic labels and themes. A total of 63,809 unique tweets were analyzed and clustered semantically into 16 topics. The public perception of healthy ageing could be broadly grouped into three themes: (1) healthy diet and lifestyle, (2) maintaining normal bodily functions and (3) preventive care. While most perceptions dovetail WHO’s definition, there are some points regarding skin appearances, beauty and aging that should be closely considered in the design of initiatives in the UN Decade of Healthy Ageing and beyond.

1. Introduction

By 2050, the population of people aged 60 years and above will double to more than two billion [1]. As the world’s population is greying rapidly, an ageing global population is one of the most pertinent social and medical demographic problems worldwide [2]. In a

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<https://doi.org/10.1016/j.heliyon.2023.e13118>

Received 27 September 2022; Received in revised form 17 January 2023; Accepted 18 January 2023

Available online 21 January 2023

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bid to support, promote and sustain healthy ageing, the World Health Organization (WHO) started the initiative on healthy ageing from 2016 to 2020, which has now continued into the United Nations (UN) Decade of Healthy Ageing 2021–2030 [2]. The WHO Member States and Partners for Sustainable Development Goals have proposed various strategies as part of the Action Plan for Ageing and Health [2]. The WHO has also established key priorities such as “promoting research on healthy ageing, aligning health systems to the needs of older people, laying the foundations and ensuring the human resources necessary for long-term integrated care, undertaking a global campaign to combat ageism, and enhancing the global network for age-friendly cities and communities” [2]. The Decade of Healthy Ageing also seeks to address four areas for action: 1. age-friendly environments, 2. combatting ageism, 3. integrated care, and 4. long-term care [3].

WHO broadly defines ‘healthy ageing’ as the process of developing and maintaining the functional ability that enables wellbeing in older age, with functional ability comprising the health-related attributes that enable people to be and to do what they have reason to value, while wellbeing is considered in the broadest sense and includes domains such as happiness, satisfaction and fulfilment [4].

Burgeoning research into healthy ageing and healthy ageing communities have highlighted that the concept of healthy ageing encompasses a plurality of views and has multidimensional and multi-faceted domains [5–9]. It is thus vital to understand the public’s perception and clarify their interpretations of ‘healthy ageing’, especially as the public is a key stakeholder in healthy ageing policies. Moreover, the Decade of Healthy Ageing is an UN-wide initiative that involves international action and requires a whole-of-government and whole-of-society effort [3,10]. The WHO, UN and other public health authorities have been working doggedly to ameliorate the effects of demographic changes, in particular the increased demand for health services for the management of chronic conditions [11] and frailty in the older adults [12], through a life-course approach.

Twitter is a social media platform that enjoys broad usership with multiple strata of the population, including the elderly [13]. Previous studies have found qualitative analysis of tweets to be a feasible and novel method to glean insights into public perceptions and emotional manifestations on a topic [14,15]. Hence, anchoring upon a transdisciplinary approach, we aimed to use unsupervised

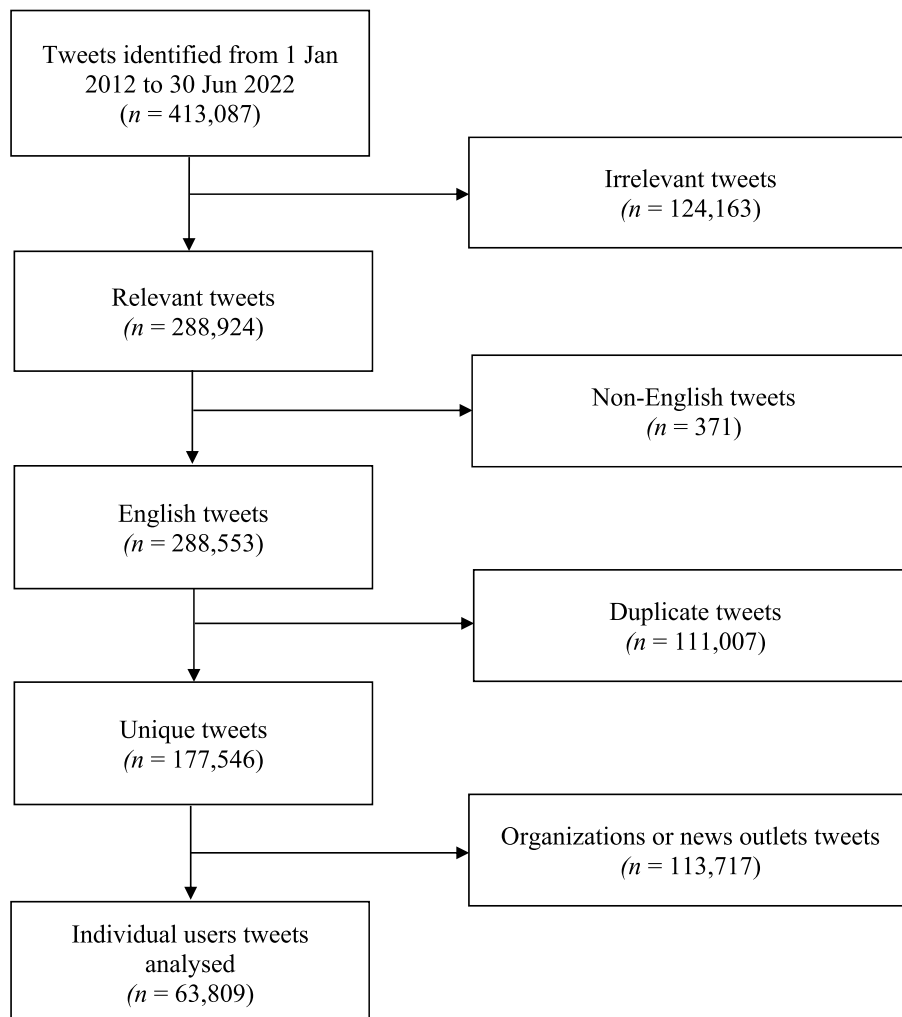


Fig. 1. Flowchart illustrating the tweets abstraction and selection process.

machine learning techniques and qualitative thematic analysis to study Twitter conversations on healthy ageing over the past decade and investigate what it means for the general public. It is hoped that the findings of our study would offer insights for governments, organisations and societies to better tailor healthy ageing policies' aims and to uncover discrepancies (if any) between the public perception of 'healthy ageing' and the goals of the UN Decade of Healthy Ageing.

2. Methods

The methodology for the present study was adapted from previous studies [15,16]. We extracted original tweets containing the terms “Healthy Ageing” OR “healthy aging” OR “healthyageing” OR “healthyaging” and posted in English language between 1 January 2012 and 30 June 2022 (both dates inclusive). Retweets and duplicate tweets were excluded from the study. Bidirectional Encoder Representations from Transformers (BERT) Named Entity Recognition [17] was then applied to select individual users only. Topic modelling, specifically BERTopic [18] was used to generate interpretable topics and descriptions pertaining to the public perception and understanding of the concept of healthy ageing. BERTopic achieves this through the use of BERT embeddings and class-based term frequency–inverse document frequency (TF-IDF). R (version 3.6.3) and Python (version 3.7.13) were used for all quantitative analyses.

Qualitative thematic analysis was then performed inductively and iteratively by the study investigators, with independent reviews of the topic labels and themes. As guided by Braun and Clarke [19], the study investigators (Q.X.N., D.Y.X.L., C.E.Y., Y.L.L. and T.M.L.) familiarized themselves with the keywords and sample tweets, produced preliminary codes, formulated predominant themes, reviewed and refined themes, defined and specified themes, and produced a write-up. Coding disagreements were resolved through discussion amongst the study team until a consensus was reached.

This study did not directly involve human participants. The outline of the study was presented to the SingHealth Centralised Institutional Review Board (CIRB), who concluded that the study did not constitute human biomedical research requiring research ethics committee review. All data used in the present study were collected according to Twitter's terms of use.

3. Results

A total of 413,087 initial tweets were identified in the specified study. A flowchart illustrating the tweets selection process with the help of unsupervised machine learning technology was shown in Fig. 1. Fig. 2 showed a map of the macro-areas of origin of the tweets. Predictably, most of the tweets originated from North America and Europe, corresponding to the general demographic of English-speaking Twitter users.

BERTopic generated 16 topics related to the public perception and understanding of healthy ageing and the total prevalence of these 16 topics was 82.3%; the remaining 17.7% was from a topic that was omitted from the current results as the BERT natural language processing (NLP) model generates a Miscellaneous topic that groups all remaining (unfitted) tweets together. Thematic analysis grouped the 16 topics into three major themes. Table 1 contained the details of the topics and sample tweets within each theme.

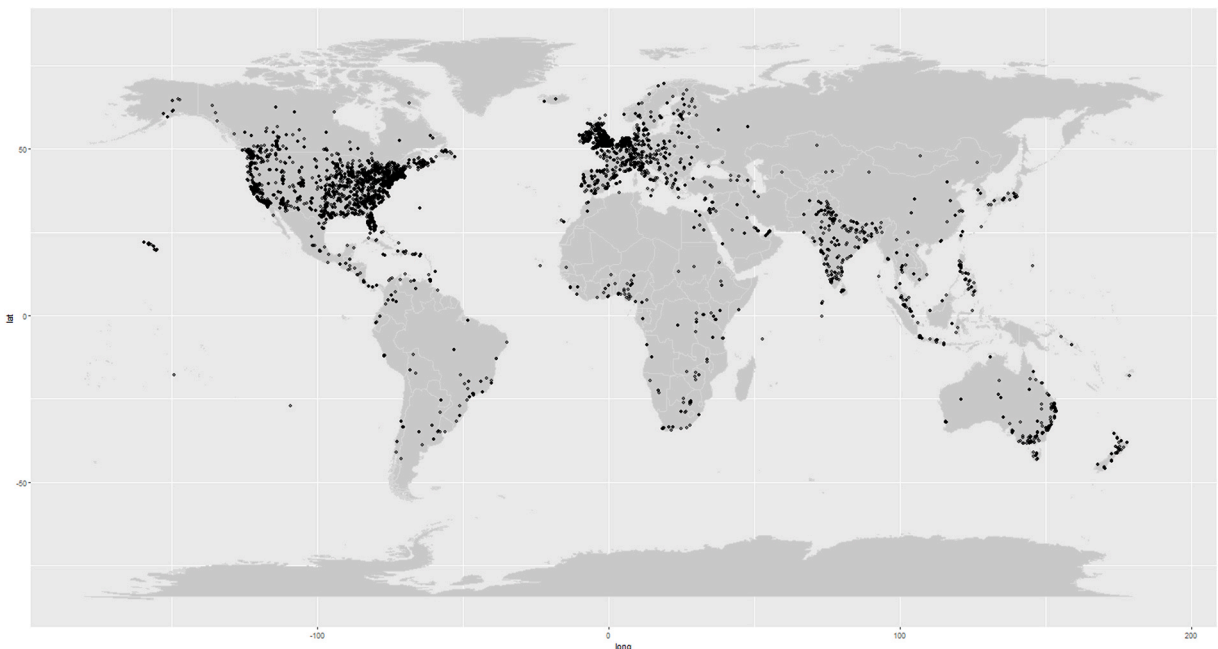


Fig. 2. Geographical locations of the tweets included in this study (each tweet is indicated by a black dot in the map).

Table 1

Themes related to the public perception of healthy ageing, along with the respective topics and sample tweets (N = 63,809).

Theme and topic (<i>keywords</i>)	Sample tweets	Number of tweets, n (%)
Theme 1: Healthy diet and lifestyle are components of healthy ageing		
Topic 1: Eating well (<i>health, active, exercise, care, research, nutrition, tips, innovation, active healthy, living</i>)	“Eat Well but Not More than You Need Great meals are a component of our happy days as we progress through life. However, it is not just eating good meals that can promote healthy aging.” “The Face of Healthy Aging #Diet #Health” “An underserved area of food: meeting the nutritional needs of older adults to inspire healthy aging. Excellent report”	41,719 (65.4)
Topic 4: Health benefits of yoga (<i>yoga, yoga healthy, yoga healthy aging, aging yoga, healthy aging yoga, pose, yoga yoga, aging yoga healthy, baxter, yoga yoga healthy</i>)	“#meditate and change your life #freedom #spirit #yoga #healthyaging” “Week two of YogaMotion for Healthy Aging is about to begin” “#HealthyAgeing: Yoga for all ages, fitness levels, instructors say:”	818 (1.3)
Topic 5: Health supplements (<i>supplements, vitamins, vitamin, nutraceuticals, healthy aging nutraceuticals, aging nutraceuticals, supplement, product, supports, anti</i>)	“Check out this great supplement which helps with healthy aging” “Healthy Aging with Vitamins and Supplements The aging progression in our bodies is an on going thing eac.” “Vitamin supplement vital for healthy aging Drink Asea: A vitamin supplement is a vital part of healthy aging. ...”	780 (1.2)
Topic 6: Arts and music (<i>arts, music, dance, arts promote, arts promote healthy, using arts, creativity, using arts promote, using, promote</i>)	“Using #Arts to Promote #HealthyAging. #ArtsMatter #ArtsHeal #MusicHeals #ArtfulLiving #Creativity” “Important and inspiring! Using the Arts to Promote Healthy Aging via #creativity #aging #health” “Overjoyed to see amazing artwork being created at #AALForum. With this in mind, shouldn't we also be focusing on how the #arts and creative activities can be integrated with technology for healthy ageing? #creativity”	790 (1.2)
Topic 7: Healthy ageing month (<i>aging month, healthy aging month, september, september healthy, september healthy aging, tips, healthyagingmonth, month september, celebrate, national</i>)	“September is #Healthy Aging Month. Objective? Taking responsibility for one's health. Physically, socially, mentally or financially.” “healthmedx: September is Healthy Aging month, and today is Aging Awareness Day! CDC says life expectancy for 75yos increased 1 mo/ year 200” “September is Healthy Aging month! Right on!”	775 (1.2)
Topic 9: Social integration (<i>loneliness, social, isolation, social isolation, friends, health, connections, loneliness isolation, social connections, wellbeing</i>)	“Social connections helping people to live well and age well #healthyaging” “Intergenerational interactions is a Win-Win to reduce #SocialIsolation and recognize the importance of keeping social connections for #HealthyAging at every age!” “Social activities key to healthy aging”	540 (0.8)
Topic 14: Healthy ageing events (<i>tour, ageing tour, healthy ageing tour, stage, race, stage healthy, stage healthy ageing, aging tour, healthy aging tour, Netherlands</i>)	“The Healthy Ageing Tour is one of few woman s stage races. I hope the global coverage of this year s race has shown how exciting and harsh this small women s race actually is. Welcome, new viewers to women s stage racing in the Netherlands! #HAT21” “#hat2017 Floorball at THE Finish HealthyAgeing-Prof ladies Cycling tour 2017 Stadskanaal Netherlands. Floorball side event” “Agree fully with this. A shame that the focus has been diverted from funding coverage of the Healthy Ageing Tour. Coverage grows the sport and attracts sponsors, rather than reinforcing the already successful.”	406 (0.6)
Theme 2: Maintaining normal bodily functions		
Topic 2: Mental cognition and brain health (<i>brain, dementia, alzheimer, memory, cognitive, brainhealth, alzheimers, brain health, aging brain, exercise</i>)	“#Aging gracefully: Keeping your #brain healthy as you age #HealthyAging #HealthyEating #Exercise” “I completely agree! Learning new things keeps your brain young. #healthyaging #brainhealth #explore” “Here at #MIFHS pushing the conversation forward re: holistic brain health. This dovetails quite nicely with the newly launched Healthy Brain Initiative: Road Map Alzheimer's Disease and Healthy Aging”	2756 (4.3)
Topic 8: Maintaining skin appearance (<i>skin, skincare, beauty, aging skin, healthy aging skin, skin care, anti, healthyliving, wrinkles, antiaging</i>)	“Successful and Healthy Aging begins with your mindset and a good skin care regime. While we don t have a ...” “Healthy ageing for everyone #stretchmarks #skincare” “These are the anti-ageing products you need to keep your neck looking great #Ageing #healthyaging #healthyliving”	738 (1.2)
Topic 10: Hearing impairment (<i>hearing, hearingloss, gerotwitter, hearing loss, hearinghealthequity, audpeeps, loss, hearingcare, publichealth, hearingloss healthyaging</i>)	“We need to address #HealthPolicy reforms to expand the accessibility; affordability of #HearingCare services; devices More about HEARS: PS: I've known Anne Madison for years; she's wonderful! #HearingHealthEquity #HealthyAging #HearingLoss” “Our sense of #hearing lets us collect, process and interpret sounds without conscious effort and people take this extraordinary ability for granted. #HealthyAging” “DEEP SLEEP is essential for healthy aging! Be careful with MELATONIN. It is actually a hormone and not something ...”	431 (0.7)
		433 (0.7)

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Table 1 (continued)

Theme and topic (keywords)	Sample tweets	Number of tweets, n (%)
Topic 11: Maintaining sleep (<i>sleep, sleep healthy, sleep healthy aging, healthy sleep, world sleep, world sleep day, sleep day, healthy sleep healthy, worldsleepday, good sleep</i>)	“Quality Sleep Can Promote Healthy Aging” “#Early to Bed, Early to Drop #Pounds. Quality #sleep can promote #healthyaging.”	
Topic 12: Gut health (<i>gut, microbiome, gut microbiome, microbiota, bacteria, gut bacteria, healthy gut, gut microbiota, probiotics, aging gut</i>)	“If you are ‘ridiculously healthy’ & 90, your gut bacteria looks the same as a 30 year-olds! Does healthy gut = healthy aging or vice versa?” “Research shows that a healthy gut can reduce anxiety and support brain function! Having a healthy microbiome is also essential to healthy ageing! #brainhealth #antiageing #probiotics #prebiotics #workwithjules #support #supple” “Healthy aging: Gut bacteria may prevent disease #PrecisionMedicine #healthcare #aging #microbiome”	430 (0.7)
Topic 13: Bone health (<i>bone, osteoporosis, bones, arthritis, pain, health, bone health, musculoskeletal, joints, osteoarthritis</i>)	“No more achy knees for me!! Healthy aging, active joints and younger looking skin! #investinginmyself” “Support Healthy Aging With Joint Support Advanced Keep an active, healthy lifestyle at any age. Protect and ...” “Joint pain doesn’t mean #arthritis. diagnosis can tell you, and which of the 50+ type you may have. #healthyaging”	415 (0.7)
Theme 3: Preventive care		
Topic 3: Genetic contributions (<i>genes, longevity, cells, genetic, cell, stem, genetics, gene, biomarkers, human</i>)	“Gene Variants are Just Not Important Enough to be Interesting in the Matter of Human Life Span #healthyaging” “More #Longevity #Ageing #HealthyAging #HealthyYears A #curatedthread. An overview @ #ageing. Understanding healthy #OlderAdults at the molecular level, combined with understanding #ageing #animal models might lead the way to healthy #aging for ALL.” “An Interview with George Church on Gene Therapy and the Treatment of Aging as Medical Condition #healthyaging”	803 (1.3)
Topic 15: Immunization against flu and other respiratory viruses (<i>covid, covid 19, 19, covid19, pandemic, flu, vaccines, adults, vaccine, health</i>)	“UN Ambassador Hoshino of Japan and speaking on the importance of ending immunization inequality and #G20 leadership on life course#vaccinesforall #healthyaging” “Healthy aging is important! An annual #FluVax is 1 step for helping maintain your health #FluShotChallenge” “The implementation of the Immunization Agenda 2030, Global strategy to accelerate the elimination of cervical cancer, and global plan of action of the Decade of Healthy Ageing 2021 2030.”	345 (0.5)
Topic 16: Preventing falls (<i>falls, fall, prevention, falls prevention, fall prevention, fallsprevention, fallprevention, balance, prevent falls, prevent</i>)	“#StopMeFromFalling When I first read this, the first thing that came to mind as a physio was whether it was a plea from older people! Opportune moment for a great shout out to physios to address #fallsprevention #frailty #activelifestyle #longevity #healthyaging” “Falls prevention is key for healthy aging. #Bladder issues like nocturia may be a driver of falls& fractures. #HealthyAging2015” “Falling is not an inevitable consequence of #aging writes Jane Brody #Falls #healthyaging”	356 (0.5)

4. Discussion

In the present study, we adopted a novel methodology, involving the use of unsupervised machine learning to analyse a large volume of free-text data from social media tweets with content related to healthy ageing, and further categorised the arising broad themes through inductive and iterative thematic analysis. Based on the topics generated by semantic clustering, the public perception of healthy ageing could be broadly grouped into three themes: 1. healthy diet and lifestyle, 2. maintaining normal bodily functions and 3. preventive care (Fig. 3).

It is perhaps not surprising that the public perceives a healthy diet and lifestyle to be components of healthy ageing. The contributions of a healthy diet and lifestyle to healthy ageing dovetail WHO’s definition. A healthy diet (Topics 1 and 5), physical activity (Topic 4) and staying engaged with organised activities (Topics 9 and 14) could help maintain good physical health and maintain mobility. Engaging in creative pursuits (Topic 6) and social interactions (Topic 9) could improve moods and increase self-esteem, thus enabling wellbeing [20–22]. The public’s ready appreciation of this aspect is expected, in light of the rise in wellness trends and the increasing emphasis on taking responsibility for your own health [23].

In a similar vein, striving to maintain one’s normal bodily functions is aligned with WHO’s conceptualisation of healthy ageing. These include gut, bone and brain health (Topics 2, 12 and 13), sensory functions like hearing (Topic 10), as well as sleep (Topic 11). Maintaining one’s physical health would enable older adults to continue to partake in activities they find meaningful. On a more subjective note, maintaining one’s appearance could be considered to be in agreement with WHO’s definition of healthy ageing. Many consider maintaining a healthy lifestyle to be essential to ageing gracefully [24]. Related to this, the upkeep of one’s skin appearance (Topic 8) may play into the societal standards of beauty, for example having no wrinkles [25]. Although this has no objective benefits for older adults’ bodily functions, maintaining one’s appearances could be part of societal perception of ageing gracefully as

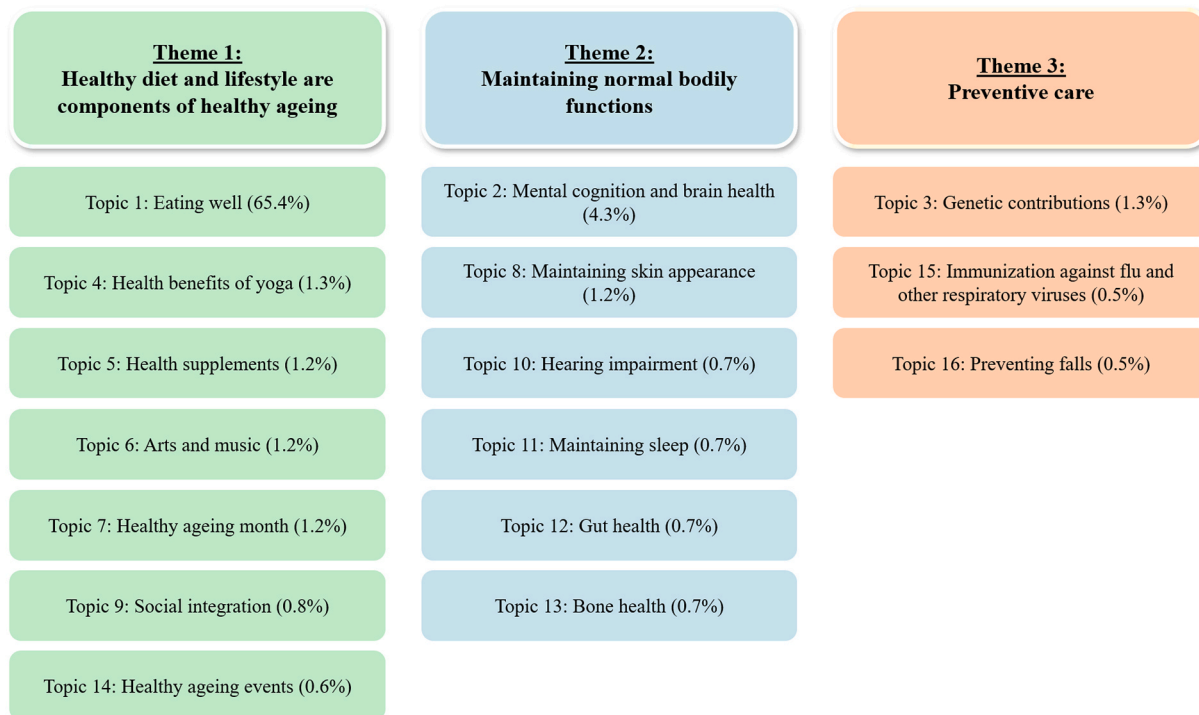


Fig. 3. Classification of themes and topics uncovered in the present study (percentages represent the prevalence of the individual topics).

highlighted by prior studies [26,27], and contributes towards personal satisfaction with one's looks and improved self-esteem [28].

The systemic factors of immunizations and fall prevention are also in line with WHO's interpretation of healthy ageing. Annual vaccinations for flu and other respiratory viruses (Topic 15) help to strengthen the immunity of older adults, protecting them against severe illnesses and complications. Fall prevention (Topic 16) protects against injury and is vital in protecting the health of older adults, as a single fall may cause a hip fracture and seriously threaten the independence, morbidity and mortality of an elderly [29]. Both immunizations and fall prevention are relevant for older adults to stay in good physical health, enabling them to participate in activities they find value in. All these elements are encapsulated in the early definition of successful ageing as laid out by Rowe and Khan, which has three main components: low probability of disease and disease-related disability, high cognitive and physical functional capacity, and active engagement with life [30].

There were also tweets exploring the genetic contributions (Topic 3) to healthy ageing. Underlying these tweets is the implication that epigenetics may be in part responsible for healthy ageing and preventive care is necessary. Since this recognises environmental interactions with the genome, this public perception is relevant to the WHO's interpretation of healthy ageing.

Collectively, Themes 1 to 3 reflect the public's understanding of personal and systemic contributions to healthy ageing. This is similar to what has been laid out by the UN and its partners in the Decade of Healthy Ageing. These findings would suggest a high public receptivity towards healthy ageing, which could result in a cooperative target audience for initiatives in the Decade. The aligned public understanding bodes well for the participation and involvement of public partners in such initiatives.

However, while Topic 8 could be considered healthy ageing, it may also toe the line of ageism, which is something the Decade aims to reduce [3,10]. By implicitly condoning the negative judgement of wrinkles, this implies the acceptance of prejudice against older adults whose skin sags and have imperfections. Care ought to be taken in the portrayal of persons in media ageing gracefully (focusing more on internal than external qualities) and less emphasis on appearance-focused qualities. A gracefully aging face is a beautiful thing. The ageist paradigm would see aging as sagging skin and decrepitude, instead of framing it with the positives such as gains in wisdom, knowledge and optimism.

Notably, missing from the public chatter are crucial elements and key words of healthy ageing as uncovered by previous research. This includes words such as "frailty", "elder abuse", "elder neglect" and "ageing in place" [31–33]. Although the hashtag '#frailty' did show up in some tweets under Topic 16, and the concept of frailty probably involves maintaining bone health (Topic 13) and falls prevention (Topic 16), besides just maintaining normal physiological functions, frailty also profoundly relates to one's feelings of vulnerability and mental and physical resilience despite physiological decline, illness and injury [34]. The issue of elder abuse and elder neglect was also conspicuously missing from the topics, topic labels and key words in the present machine learning analysis. Healthy ageing should also cover ageing in place and robust social support in the living environment, which reduces the need for institutionalisation. However, the use of the phrase "ageing in place" did not appear in our analysis. This makes one wonder about the representativeness of the findings as certain demographics may not have been captured, including the elderly suffering in silence. It may also be possible that these terms are more commonly used among academics and practitioners rather than by laypersons in the

public sphere. There are multi-level contexts and making sense of the public perceptions may also require more information than what is contained in the tweets per se.

Accordingly, the study finding should be interpreted in light of the following limitations. First, as the concept of healthy ageing has also been co-opted by mass media, some tweets included in our sample appeared to be advertisements and product placements that were commercial in nature, e.g. “Book for your free Aesthetic consultation to find a solution to your ageing Skin. #drugs #health-yaging”. While we excluded tweets by organisations, we were unable to exclude individual users who had commercial interests and personally advertised their product. This could have distorted our findings. Second, our results at least in part reflect the perception of healthy ageing among Twitter users, but may not necessarily represent the general population. Most of the tweets in the present study were from users in North America and Europe, with some countries being under-represented possibly due to national bans on the use of Twitter (e.g. China, Iran and Turkmenistan) [35], even though these countries are also member states of the UN. In addition, only tweets in English were included, and several UN member states do not use English as their first or main language. Future work could also include tweets in other languages and analyse other social media platforms, e.g. Facebook.

5. Conclusions

In conclusion, the present study examined the key public perceptions of healthy ageing, as represented by Twitter users, and while most perceptions dovetail WHO’s definition, there are some points regarding the public perception of beauty that should be taken into consideration sensitively in the design of initiatives in the UN Decade of Healthy Ageing and beyond. In agreement with the findings of the study and frequently used conceptualizations of healthy ageing, the general priority areas for action should rightly include lifestyle interventions, promoting self-care, falls prevention, and influenza immunization.

Author contribution statement

Qin Xiang Ng, MBBS, MPH; Tau Ming Liew, MBBS, PhD: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dawn Yi Xin Lee; Chun En Yau: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yu Liang Lim, MBBS: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available from the corresponding author, Tau Ming Liew, upon reasonable request.

Declaration of interest’s statement

The authors declare no competing interests.

Acknowledgements

None.

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