



OPEN ACCESS



Check for updates

Association between financial links to indoor tanning industry and conclusions of published studies on indoor tanning: systematic review

Lola Adekunle,¹ Rebecca Chen,¹ Lily Morrison,¹ Meghan Halley,¹ Victor Eng,¹ Yogi Hendlin,² Mackenzie R Wehner,^{3,4} Mary-Margaret Chren,⁵ Eleni Linos¹

¹Department of Dermatology, Stanford University, Palo Alto, CA 94305, USA

²School of Philosophy Erasmus University, Rotterdam, Netherlands

³Department of Dermatology, University of Pennsylvania, Philadelphia, PA, USA

⁴Departments of Health Services Research and of Dermatology, University of Texas MD Anderson Cancer Center, Houston, TX, USA

⁵Department of Dermatology, Vanderbilt University Medical Center, Nashville, TN, USA

Correspondence to: E Linos
linos@stanford.edu
(or @linos_eleni on Twitter;
ORCID 0000-0002-5856-6301)

Additional material is published online only. To view please visit the journal online.

Cite this as: *BMJ* 2020;368:m7
<http://dx.doi.org/10.1136/bmj.m7>

Accepted: 17 December 2019

ABSTRACT

OBJECTIVE

To assess whether an association exists between financial links to the indoor tanning industry and conclusions of indoor tanning literature.

DESIGN

Systematic review.

DATA SOURCES

PubMed, Embase, and Web of Science, up to 15 February 2019.

STUDY SELECTION CRITERIA

Articles discussing indoor tanning and health were eligible for inclusion, with no article type restrictions (original research, systematic reviews, review articles, case reports, editorials, commentaries, and letters were all eligible). Basic science studies, articles describing only indoor tanning prevalence, non-English articles, and articles without full text available were excluded.

RESULTS

691 articles were included in analysis, including empiric articles (eg, original articles or systematic reviews) (357/691; 51.7%) and non-empiric articles (eg, commentaries, letters, or editorials) (334/691; 48.3%). Overall, 7.2% (50/691) of articles had financial links to the indoor tanning industry; 10.7% (74/691) articles favored indoor tanning, 3.9% (27/691) were neutral, and 85.4% (590/691) were critical of indoor tanning. Among the articles without industry funding, 4.4% (27/620) favored indoor tanning, 3.5% (22/620) were neutral, and 92.1% (571/620) were critical of indoor tanning. Among the articles with financial links to the indoor tanning industry, 78% (39/50) favored indoor tanning, 10%

(5/50) were neutral, and 12% (6/50) were critical of indoor tanning. Support from the indoor tanning industry was significantly associated with favoring indoor tanning (risk ratio 14.3, 95% confidence interval 10.0 to 20.4).

CONCLUSIONS

Although most articles in the indoor tanning literature are independent of industry funding, articles with financial links to the indoor tanning industry are more likely to favor indoor tanning. Public health practitioners and researchers need to be aware of and account for industry funding when interpreting the evidence related to indoor tanning.

SYSTEMATIC REVIEW REGISTRATION

PROSPERO CRD42019123617.

Introduction

The science on artificial ultraviolet light, indoor tanning, and health is complicated, partly because of the large variation in published studies that differ in their conclusions on the risks or benefits to health of indoor tanning. Some studies conclude that indoor tanning is a health risk, focusing on increased risk of malignant melanoma, basal cell carcinoma, and squamous cell carcinoma, and describe how use of indoor tanning is associated with drug use, alcohol misuse, smoking, depression, and anxiety.¹⁻⁵ However, some studies conclude that risks of indoor tanning are not established or focus on potential health and cosmetic benefits including relaxation, appearance, sun protection through a “base tan,” and higher serum concentrations of vitamin D metabolites.⁶⁻⁸ The science is further complicated by the fact that artificial ultraviolet therapy has been used to treat diseases such as rickets and psoriasis and because ultraviolet B from both outdoor sunlight exposure and artificial sources can produce vitamin D. Vitamin D deficiency is associated with several negative health outcomes including autoimmune disease, cancer, and cardiovascular disease in observational studies.⁹⁻¹³

Several studies have examined the role of financial conflicts of interest in the scientific literature. A growing body of evidence shows that financial conflicts of interest and funding of scientific research can influence science on a range of topics, including alcohol related morbidity and mortality, medicines, and the relation between sugar and obesity.¹⁴⁻¹⁸ Scientists have used a variety of approaches to evaluate the effect of financial conflicts of interest on scientific literature. These include investigating the influence of donations from industry on patients’ organizations,¹⁹ surveying

WHAT IS ALREADY KNOWN ON THIS TOPIC

Some scientific articles about indoor tanning focus on risks, whereas others focus on benefits

However, the association between the source of funding and conclusions of scientific articles on indoor tanning has not been well studied

WHAT THIS STUDY ADDS

These findings provide evidence of an association between financial links to the indoor tanning industry and the conclusions of scientific articles on indoor tanning

Articles with financial links to the indoor tanning industry were more likely to favor indoor tanning, emphasizing potential benefits and/or omitting risks

The study suggests that the articles funded by the indoor tanning industry favor conclusions beneficial to the indoor tanning industry

academic authors of industry funded research,²⁰ and examining tobacco industry documents.²¹

The goal of this study was to systematically and rigorously assess whether an association exists between financial links to the indoor tanning industry and the conclusions of scientific articles on indoor tanning. This is the first systematic investigation of the conflicts of interest in the indoor tanning literature. We hypothesized that articles with financial ties to the indoor tanning industry would be more likely to support indoor tanning and that this association would be present in all article types and among high impact journals.

Methods

Search strategy and selection criteria

We did a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (fig 1).²² Our protocol was registered in PROSPERO (number CRD42019123617). We did not restrict our search by date of publication, and we searched from the start of each database through 15 February 2019 (PubMed from 1940, Embase from 1949, and Web of Science from 1898).

Our search string was co-created with an academic research librarian and consisted of terms relevant to artificial ultraviolet tanning and health, without language restrictions. We considered the following terms and their variations to be synonymous with indoor tanning: sunbed, sunlamp, tanning bed, tanning booth, solarium, suntan parlor, artificial tanning, artificial ultraviolet tanning, and non-solar ultraviolet tanning. We then paired the indoor tanning terms firstly with synonyms or examples of types of skin cancer to capture health risks (eg, skin neoplasm, basal cell cancer) and secondly with synonyms or examples of types of commonly perceived benefits of tanning (eg, vitamin D, mood enhancing, phototherapy). See appendix 1 for the exact search strategy used.

Study selection and inclusion and exclusion criteria

All records obtained through database searches were imported into Covidence (www.covidence.org). Two primary reviewers (LA, RC) independently read all abstracts to assess their eligibility. Any disagreements between the two independent reviewers were settled by a third reviewer (EL) (184 (9.7%) records out of 1901 total records reviewed). Any articles that discussed indoor tanning and health were eligible for inclusion, with no article type restrictions (original research, systematic reviews, review articles, case reports, editorials, opinion pieces, commentaries, and letters were all eligible). To focus on human studies, we excluded articles if they reported basic science studies. Furthermore, we excluded articles if they described only the prevalence of indoor tanning, were in languages other than English, or were records without full text available, such as abstracts for conference proceedings (fig 1).

Blinding of funding source and financial conflict of interests

Full text articles were obtained by a different author (LM), who collected funding source information and financial conflict of interest disclosures in a separate dataset. More specifically, LM removed funding source information and financial conflict of interest disclosures from each of the full text articles by using Adobe Acrobat DC Pro 2019 software, copied this financial information, and saved it in a spreadsheet. The redacted PDF version of each article was uploaded to Covidence, blinding the primary reviewers to this information.

Data extraction

Each primary reviewer (LA, RC) independently read each blinded manuscript. Both primary reviewers (LA, RC) extracted the following data items from each full text article reviewed: authors' names, article title, date of publication, country, language, journal name, and type of article. The 2017 impact factor for each journal was added to the database.

Categorization of tanning stance

To systematically categorize the conclusions of the studies, the two primary coders first reviewed a subset of the articles and generated a list of risks and benefits mentioned in the authors' own words. The study team then reviewed this list and consolidated risks and benefits into broader categories with clear definitions (table 1). We then used this standardized list of codes to identify and categorize risks and benefits including health risks (eg, non-melanoma skin cancer and melanoma), health benefits (eg, increased serum vitamin D and possible sun protection through a "base tan"), and cosmetic and mood effects (eg, appearance, relaxation, self-confidence) of indoor tanning (table 1). Each reviewer then carefully considered which risks and/or benefits were and were not mentioned (eg, skin cancer, serum vitamin D), the magnitude of risks and benefits mentioned in terms of their potential effect on human health (eg, improved mood versus skin cancer), how the relations between these various outcomes (both risks and benefits) and indoor tanning were described and/or questioned (eg, highlighting causal relations versus associations), the degree of certainty ascribed to these relations (eg, definitive versus weak), and which sources of potential bias were emphasized over others (eg, the type of tanning bed used, length of exposure to ultraviolet). After taking all of these elements into account, each independent reviewer selected what s/he deemed to be the most appropriate category for each article on a scale of 1 (strongly in favor of tanning) to 5 (strongly critical of tanning) (see table 2). In addition, each rater kept a note of the key elements underlying his/her rating. Reviewers did not make a judgment about whether statements included in manuscripts were factually true or false; instead, they focused on the overall stance of the article based on the criteria described. Examples of studies included in each category with relevant quotes are shown in

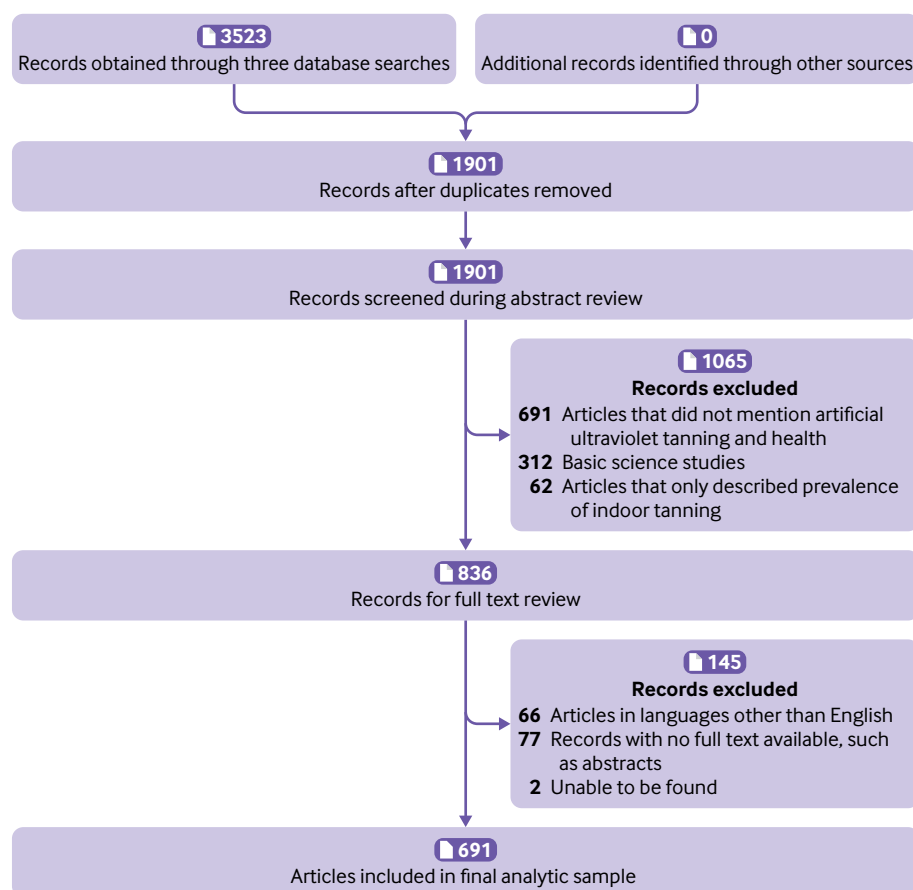


Fig 1 | PRISMA flow diagram

appendix 2. Other studies have used this method for systematic reviews examining mixed sets of article types to assess article stance—for example, a recent systematic review examining conflicts of interest in the tobacco harm reduction literature.²³

The rate of agreement within the three primary categories of the scale (in favor (1, 2), neutral (3), or critical (4, 5)) was 97.0% (670/691). If the two independent reviewers disagreed on the article's overall conclusion (eg, if one reviewer scored it as neutral, whereas the other scored it as in favor of tanning), this article was re-reviewed by a third reviewer (VE) and the average of the three reviewers was used as the final score (n=22). By averaging the scores of the three reviewers into one final score, each reviewer's score was given equal weight. The Cohen's kappa for the inter-rater reliability when classifying papers as in favor (1-2) versus not (3-5) was 0.90. We assessed the inter-rater reliability for the scores by using a two way, agreement, average measures intra-class correlation. We observed a high correlation of 0.92 (95% confidence interval 0.885 to 0.939), which indicates high agreement between the two raters.

Analysis of funding

After full text review and data extraction were completed, we created the final analytic dataset by merging the funding source information and financial

conflict of interest disclosures data with the main dataset containing article and journal descriptors and tanning stance scores (appendix 3). We defined financial links to industry on the basis of disclosed funding source information and/or conflict of interest disclosures. Because authors may not always disclose conflicts, and not all publications require conflict of interest disclosures, we also attempted to identify articles written by authors who had disclosed financial conflicts in other publications. The types of financial links to industry are listed in table 3 and include four categories: studies that disclosed funding or support by an indoor tanning device company (category A, defined as a company directly involved in the manufacturing or sale of indoor tanning devices), an industry supported organization (category B, defined as an organization that publicly states on its website that it has received funding support from or is associated with the indoor tanning industry), or a pharmaceutical company that manufactures vitamin D (category C, including pharmaceutical companies that manufactured vitamin D supplements for an indoor tanning study) and studies written by one or more authors who previously declared a conflict of interest or financial tie to any company in category A or B in another paper (category D). We created category D after the initial identification of article authors falling into category A or B. We reviewed the entire database to identify any additional

Table 1 | Categorization scheme of health themes

Theme	Definition
Benefit theme	
Phototherapy	Mentions any dermatologic skin disease that is treated with artificial ultraviolet
Photoprotection	Mentions how increased artificial ultraviolet tanning leads to epidermal changes or increased melanin that may give greater protection against ultraviolet
Source of vitamin D/bone health	Mentions that artificial ultraviolet leads to increased vitamin D and/or greater bone health
Physical attractiveness/cosmetic reasons	Mentions that artificial ultraviolet tanning improves appearance
Cancer prevention	Mentions that vitamin D has been associated with prevention of non-cutaneous cancer
Mood effects	Mentions that artificial ultraviolet tanning will lead to greater relaxation, stress reduction, or improved mood or self-esteem
Pain relief	Mentions that artificial ultraviolet tanning is able to alleviate pain
Lowers blood pressure	Mentions that artificial ultraviolet tanning helps to lower blood pressure
Endorphin generation	Mentions that endorphins are generated by use of artificial ultraviolet tanning
Risk theme	
Development of skin cancer	Mentions that artificial ultraviolet leads to development of skin cancer (NMSC or melanoma)
Accelerated aging	Mentions that artificial ultraviolet leads to increased skin wrinkles, leathery skin, age spots, or any other markers of aging skin
Addictive potential	Mentions use of artificial ultraviolet tanning being linked to behavior that may be addictive
Ocular damage	Mentions any type of harm to the eye due to artificial ultraviolet tanning (cataracts, melanoma)
DNA damage	Mentions artificial ultraviolet tanning causing damage to or molecular change in DNA
Other skin disease (SLE, pruritus, dryness, photodrug reaction)	Mentions artificial ultraviolet tanning causing skin reaction (allergic rash, pruritus (itching), dryness, or lupus-like rash)
Immunosuppression	Mentions how artificial ultraviolet can cause suppression of immune system
Hypervitaminosis D	Mentions how artificial ultraviolet can increase vitamin D concentrations above upper limit of normal
Cutaneous burn/erythema	Mentions artificial ultraviolet causing sunburns or increased erythema of skin causing pain

NMSC=non-melanoma skin cancer; SLE=systemic lupus erythematosus.

manuscripts that did not disclose industry funding but were written by co-authors who also were authors for articles linked to category A or B (indoor tanning device company or indoor tanning association). We identified 18 additional papers that involved eight authors who are listed in table 3, along with their disclosure statements. We considered articles that did not disclose industry links or did not include authors identified as previously linked to industry funding to be independent of industry funding.

To investigate the hypothesis that the association between conflict of interest and an article's stance may be less strong in original articles, high impact journals, or earlier years, we assessed whether our primary outcome varied by article type, impact factor, or date of publication. We classified articles as empiric if they were original research articles, randomized trials, systematic reviews and meta-analyses, or research letters. We classified articles as non-empiric if they were commentaries, responses, viewpoints, letters to the editor, case reports, non-systematic reviews, or editorials. We did descriptive analyses stratifying by stance on tanning, publication date (before and after 1990), financial links, impact factor, and publication type.

We calculated risk ratios and confidence intervals to examine the association between financial links to the indoor tanning industry (categories A, B, and

D) and the manuscript's stance on tanning. To assess whether our conclusions changed according to our definition of financial links to the tanning industry, we did sensitivity analyses by varying the definition of financial links to industry to only articles in categories A and B, articles in categories A-C, or articles in any of the four categories. To examine potential heterogeneity by date of publication, article type, and journal impact factor, we did secondary analyses stratifying by these characteristics. We chose to estimate risk ratios and Cohen's statistics, as probabilities are more interpretable than odds.

Patient and public involvement

This research was done without patient or public involvement, as neither was relevant to the research aims. Patients were not invited to comment on the study design and were not consulted to interpret the results or develop this manuscript.

Results

We obtained a total of 3523 records through the three database searches (PubMed, Embase, Web of Science); 1622 duplicates were removed, either automatically by Covidence or manually, leaving 1901 records that were screened by reviewers (fig 1). During screening of abstracts, we excluded 1065 articles because they did not mention artificial ultraviolet tanning and health (n=691), were basic science studies (n=312), or described only the prevalence of indoor tanning (n=62). After screening of abstracts, 836 records remained for full text review and coding. During full text review, we excluded articles in languages other than English (n=66) and records with no full text available, such as abstracts from conference

Table 2 | Scale of tanning stance

Score	Stance on indoor tanning
1	Strongly favors tanning
2	Favors tanning
3	Neutral/mixed
4	Critical of tanning
5	Strongly critical of tanning

Table 3 | Categories of financial links to industry described in manuscript's source of funding information and/or financial conflict of interest disclosures sections, with evidence of link

Name of group, company, or individual	Example of link to industry
Indoor tanning device companies	
Amber Leisure Ltd	https://www.europages.co.uk/AMBER-LEISURE-LTD/GBR010993-00101.html
Dan-Sun	https://www.europages.co.uk/DANSUN-APS/DNK028667-00101.html
KBL-Solarien AG	https://www.leisuremanagement.co.uk/detail.cfm?pagetype=detail&subject=companydetail&co_code=31331678 http://unsafeproducts.eu/recall/165509-kbl-solarien-ag-sun-bed-megasun-4000
Nordic Solarium Ltd	https://nordic.co.uk
Philips Lighting	https://www.lighting.philips.com/main/products/special-lighting/phototherapy ; http://www.tanninglamps4less.com/philips.html
Sperti Sunlamps (KBD, inc)	https://www.sperti.com
Summertan Netherlands	https://www.summertan.nl
Wolff System Technology Corporation	http://www.wolffsystem.com/about.html
Industry supported organizations	
American Suntanning Association	https://americansuntanning.org/about-us/
Association of Sun Tanning Operators Ltd	https://europepmc.org/backend/ptpmcrender.fcgi?accid=PMC1546966&blobtype=pdf
Danish Sunbed Federation	https://ec.europa.eu/health/sites/health/files/scientific_committees/emerging/docs/ev_20160412_co15_en.pdf
European Sunlight Association	http://europeansunlight.eu/about-us/
Foundation for General Light Therapy	
Indoor Tanning Association	https://www.ftc.gov/news-events/press-releases/2010/01/indoor-tanning-association-settles-ftc-charges-it-deceived ; https://www.ftc.gov/enforcement/cases-proceedings/082-3159/indoor-tanning-association-matter ; http://www.indoortanninglotion.org/indoor-tanning-association/ ; http://www.istmagazine.com/ita-update-a-fond-farewell/
Jörg Wolff Foundation	https://www.joerg-wolff-stiftung.de/en/the-foundation/the-founder/
Sunlight, Nutrition, and Health Research Center (SUNARC)	https://ec.europa.eu/health/sites/health/files/scientific_committees/emerging/docs/ev_20160412_co09_en.pdf
Sunlight Research Forum	http://www.revitalighttherapy.com/base-tans-work-sunlight-research-forum/
The Norwegian Tanning Association	-
Vitamin D Alliance	https://business-ethics.com/wp-content/uploads/2012/08/TanChart.pdf
Vitamin D Council	https://www.vitamindecouncil.org/about-us/#.XZ8AVKfMzGI ; https://www.vitamindecouncil.org/about-us/sponsors/#.XZ8AY6fMzGI
Vitamin D Society	http://www.vitamindecouncil.org/pdf/What%20is%20the%20Best%20Source%20of%20Vitamin%20D%20-%20Part%201%20-%20Marc%20Sorenson%20EdD.pdf
Ultraviolet (ultraviolet) Light Foundation	http://uvfoundation.org/2019/03/08/get-your-light-on-dark-winter-days/
Pharmaceutical companies	
Amgen	https://www.amgen.com ; https://www.nytimes.com/2018/08/18/business/vitamin-d-michael-holick.html
Anacor: acquired by Pfizer	https://www.nytimes.com/2016/05/17/business/dealbook/pfizer-to-acquire-anacor-pharmaceuticals-for-5-2-billion.html
Baxter	https://www.baxter.com ; https://www.nutraingredients.com/Article/2002/05/29/Baxter-innovates-in-dietary-supplements#
Dermapharm	https://www.dermapharm.dehttps://www.dermapharm.de/produkte.html#360/dekristol-400-i-e.html
DermTech International	https://dermtech.comhttps://www.biospace.com/article/dermtech-international-and-b-rady-children-s-hospital-san-diego-b-initiate-study-to-understand-effects-of-vitamin-d-as-a-treatment-for-atopic-derm
Boots UK (Boots the Chemists)	https://www.boots.com ; https://www.boots.com/vitabiotics-ultra-vitamin-d-2000-iu-extra-strength-10240007
Galderma	https://www.galderma.com/news/galderma-wins-fda-approval-vecical-tm-ointment
Genentech (acquired by Roche)	https://diagnostics.roche.com/global/en/products/params/electsys-vitamin-d-total-ii.html
Immundiagnostik AG	http://www.immundiagnostik.com/en/home.htmlhttp://www.immundiagnostik.com/en/home/news/product-news/product-news-articles/article/409/14.html
Leo Pharmaceuticals	http://www.leo-pharma.us/Files/Billeder/LEO_local_images/LEO-Pharma.US/PI%20-%20Dovonex%20Cream.pdf
Otsuka	https://www.otsuka-us.comhttps://www.otsuka.co.jp/en/nutraceutical/products/naturemade/
Pfizer Inc	https://www.pfizer.comhttps://www.pfizer.com/products/product-detail/caltrate
Pharma-Vinci (acquired by Axellus)	https://www.helsinki.fi/m/htimes/domestic-news/general/4184.html
Reckitt Benckiser	https://www.rb.comhttps://www.sears.com/reckitt-benckiser-schiff-glucosamine-2000-mg-plus-vitamin/p-SPM8656343511
Roche Pharmaceuticals	https://www.roche.com/media/releases/med-cor-2011-05-16t.htm
Sanofi Aventis	https://www.sanofi.ushttp://www.contactus.sanofi-aventis.us/#https://www.sanofi.in/-/media/Project/One-Sanofi-Web/Websites/Asia-Pacific/Sanofi-IN/Home/science-and-innovation/for-healthcare-professionals/product-information/DePURA.pdf
Solgar Vitamins	https://www.solgar.co.uk/all-products/vitamin-d3-1000iu/
Spirig Pharma (acquired by Galderma)	https://www.biospace.com/article/releases/galderma-pharma-s-a-world-s-leading-company-focused-exclusively-on-dermatology-acquires-spirig-pharma-ltd-/
Stiefel/GlaxoSmithKline	https://www.stiefel.comhttps://www.gsk.comhttps://www.oscal.com/products/calcium-d3/
Authors who had previously disclosed link to industry	
Dowdy JC	"RMS and JCD are paid consultants of Sperti Sunlamps on the vitamin D lamp project." (Sayre, et al. 2007)
Farr PM	"Philips Lighting supplied the lamps used in the study and also contributed to nursing salary costs and patients' travel expenses." (Das, et al. 2002)
Grant WB	"WB Grant receives funding from the UV Foundation (McLean, VA, Australia) and the Vitamin D Society (Canada) and awaits funding from the European Sunlight Association." (Grant, et al. 2007)
Holick MF	"MH serves as a consultant to the UV Foundation." (Tangpricha, et al. 2004)
Moan J	Co-author on studies funded by SUNARC (Grant, et al. 2007; Grant, et al. 2010), supported by the Norwegian Tanning Association (Porojnicu, et al. 2008) and the Ultraviolet Foundation and European Sunlight Association (Moan, et al. 2009)
Porojnicu AC	"The sun bed used in the present study was borrowed from The Norwegian Tanning Association." (Porojnicu, et al. 2008). Co-author on Grant, et al. 2007 ("WB Grant receives funding from the UV Foundation (McLean, VA, Australia) and the Vitamin D Society (Canada) and awaits funding from the European Sunlight Association.")
Sayre RM	"RMS and JCD are paid consultants of Sperti Sunlamps on the vitamin D lamp project." (Sayre, et al. 2007)
Wulf HC	"The authors are grateful to Royal Consul, Nykøbing Mors, Denmark, for lending us a sunbed during the study." (Theiden, et al. 2008)

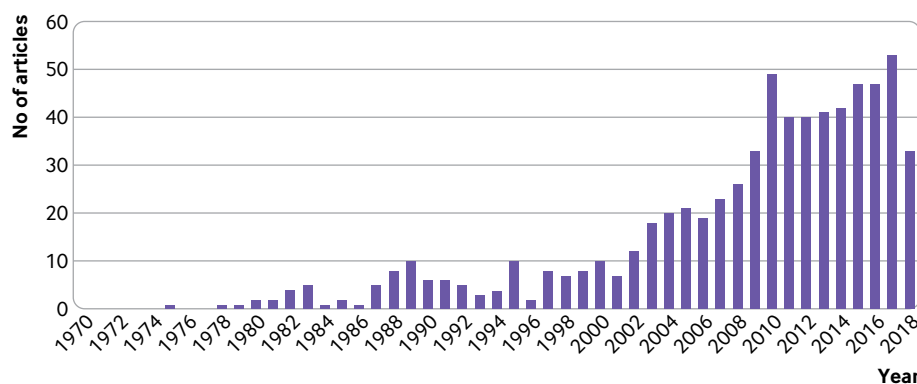


Fig 2 | Number of indoor tanning articles by year between 1970 and 2018, using final analytic sample of articles

proceedings (n=77). Two articles could not be located. The final analytic sample included 691 articles. Figure 2 shows the growing number of published scientific articles related to indoor tanning over time.

Table 4 shows the descriptive characteristics of the 691 articles included in the final analysis. Overall, 7.2% (50/691) disclosed financial links to the indoor tanning industry (indoor tanning device companies, industry supported organizations, or an author with a previous disclosure to indoor tanning industry). In terms of

stance toward indoor tanning, 85.4% (590/691) were critical of tanning (score of 4 or 5), 3.9% (27/691) were neutral (score of 3), and 10.7% (74/691) favored tanning (score of 1 or 2) (table 4). When we included articles with links to pharmaceutical companies that produce vitamin D products, 10.3% (71/691) of articles had financial links to industry and 89.7% (620/691) were independent of industry (table 4; fig 3).

Just over half (51.7%; 357/691) of articles were empiric research (original research, research letters,

Table 4 | Descriptive analysis of articles by tanning stance, financial links, impact factor, and publication type. Values are numbers (percentages)

	Total (n=691)	Stance on indoor tanning				
		1: only asserts or describes health benefits (n=12; 1.7%)	2: mostly asserts or describes health benefits (n=62; 9.0%)	3: asserts or describes health risks and benefits equally (n=27; 3.9%)	4: mostly asserts or describes health risks (n=150; 21.7%)	5: only asserts or describes health risks (n=440; 63.7%)
Financial links						
Independent	620 (89.7)	5 (0.8)	22 (3.5)	22 (3.5)	144 (23.2)	427 (68.9)
Linked to indoor tanning industry (category A+B+D)	50 (7.2)	7 (14)	32 (64)	5 (10)	3 (6)	3 (6)
Tanning bed manufacturer (A)	10 (14)	0 (0)	5 (50)	3 (30)	1 (10)	1 (10)
Industry funded organization (B)	22 (31)	6 (27)	14 (64)	1 (5)	1 (5)	0 (0)
Pharmaceutical company only (C)	21 (30)	0 (0)	8 (38)	0 (0)	3 (14)	10 (48)
Author only (D)	18 (25)	1 (6)	13 (72)	1 (6)	1 (6)	2 (11)
Impact factor						
0-5.00	368 (53.3)	8 (2)	45 (12)	9 (2)	78 (21)	228 (62)
5.01-10	202 (29.2)	1 (1)	11 (5)	15 (7)	43 (21)	132 (65)
≥10.01	59 (8.5)	2 (3)	2 (3)	0 (0)	16 (27)	39 (66)
Unknown	62 (9.0)	1 (2)	4 (6)	3 (5)	13 (21)	41 (66)
Publication type						
Empiric research:						
Original article	300 (43.4)	5 (2)	31 (10)	15 (5)	76 (23)	173 (58)
Research letter	46 (6.7)	0 (0)	1 (2)	0 (0)	6 (13)	39 (85)
Systematic review, meta-analysis	11 (1.6)	0 (0)	1 (9)	0 (0)	0 (0)	10 (91)
Total	357 (52)	5 (1)	33 (9)	15 (4)	82 (23)	222 (62)
Non-empiric articles:						
Review	121 (17.5)	2 (2)	14 (12)	4 (3)	34 (28)	67 (55)
Editorial, commentary, viewpoint, perspective	121 (17.5)	0 (0)	4 (3)	4 (3)	26 (21)	87 (72)
Case report (includes clinical challenge)	40 (5.8)	3 (8)	4 (10)	1 (3)	3 (8)	29 (73)
Letters (to the editor)	30 (4.3)	1 (3)	6 (20)	2 (7)	3 (10)	18 (60)
Comment/response	22 (3.2)	1 (5)	1 (5)	1 (5)	2 (9)	17 (77)
Total	334 (48.3)	7 (2)	29 (9)	12 (4)	68 (20)	218 (65)
Publication date						
Before 1990	44 (6.4)	2 (5)	10 (23)	2 (5)	8 (18)	22 (50)
1990 or after	647 (93.6)	10 (1.5)	52 (8.0)	25 (3.9)	142 (21.9)	418 (64.6)

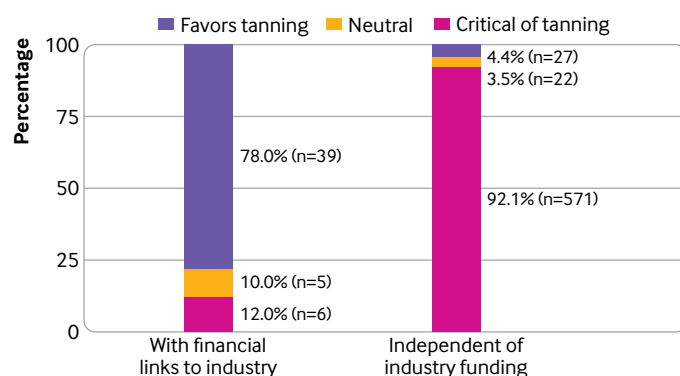


Fig 3 | Proportion of published articles on indoor tanning according to financial links and stance on indoor tanning\

and systematic reviews/meta-analyses), and 48.3% (334/691) were non-empiric research (reviews, editorials, comments/responses, letters to the editor, case reports) (table 4). The risk of a non-empiric article being labeled as “pro-tanning” was similar to that of an empiric paper (risk ratio 1.0, 95% confidence interval 0.66 to 1.6). Most papers included were published after 1990 (93.6%; 647/691). Among those published before 1990, 27% (12/44) favored tanning, 5% (2/44) were neutral, and 68% (30/44) were critical of tanning. Among the papers published in 1990 and beyond, 9.6% (62/647) favored tanning, 3.9% (25/647) were neutral, and 86.6% (560/647) were critical of tanning (table 4).

Among the articles with financial links to industry, 14% (10/71) were linked to indoor tanning device companies, 31% (22/71) were linked to an industry supported non-governmental organization, 30% (21/71) were linked to a pharmaceutical company that manufactures vitamin D products, and 25% (18/71) had an author who had disclosed a conflict of interest in another paper (either a tanning device company or an industry supported non-governmental organization). Among the articles with financial links to indoor tanning industry funding in our primary analysis (categories A, B, and D), 78% (39/50) favored tanning, 10% (5/50) were neutral, and 12% (6/50) were critical of tanning. When we included all papers with links to industry (categories A, B, C, and D), 66% (47/71) favored tanning, 27% (19/71) were critical of tanning, and 7% (5/71) were neutral (fig 3). Among the articles entirely independent of industry, 4.4% (27/620) favored tanning, 3.5% (22/620) were neutral, and 92.1% (571/620) were critical of tanning. The vast majority (93%; 55/59) of articles in high impact journals (impact factor ≥ 10) were critical of tanning. The mean journal impact factor of articles with financial links to the indoor tanning industry was similar to that of articles independent of industry funding (6.73 v 6.72).

The risk of an industry funded paper (categories A, B, and D) being labeled as in favor of tanning was 14 times higher relative to a non-industry funded paper (risk ratio 14.3, 10.0 to 20.4). We did sensitivity analyses by calculating risk ratios for various combinations of

industry funded categories (such as including papers funded by pharmaceutical companies) and for sub-samples (such as those published after 1990 and those with an above average impact factor). Each risk ratio was significantly greater than 1. Figure 4 shows all these relative risks, along with 95% confidence intervals.

Discussion

In this systematic review of 691 studies, we found a strong association between articles with financial links to the indoor tanning industry and the conclusions of scientific articles favoring indoor tanning. Overall, a minority of the literature—less than 10% of articles—reported financial links to the indoor tanning industry. However, the articles with financial links to industry were 14 times more likely to have a stance that was supportive of indoor tanning. This association persisted in sensitivity analyses that varied the definition of financial ties to industry. Also, this association persisted in sub-analyses stratifying by empiric and non-empiric articles, by date of publication, and by low and high impact journals.

Comparison with other studies

The Institute of Medicine has raised concerns about financial ties to industry potentially influencing the primary interests and goals of medicine.²⁴ Our findings are consistent with the broader literature on the relation between financial conflicts of interest and scientific research,²⁵ which has been documented in relation to several major industries, including tobacco, sugar, and pharmaceuticals. More than 20 years ago, scientists documented that affiliation of authors with the tobacco industry was highly associated (odds ratio 88.4) with a conclusion that passive smoking is not harmful, even after control for article quality, peer review status, article topic, and year of publication.²⁶ A recent systematic review reached a similar conclusion when examining conflicts of interest in the tobacco harm reduction literature (use of e-cigarettes, smokeless tobacco, etc), which found that 80.9% of articles funded by the tobacco industry endorsed these alternatives, compared with only 41.1% of non-industry funded articles.²³ A study by Kearns et al showed the sugar industry’s role in downplaying the importance of sugar as a cause of coronary heart disease, as well as the sugar industry’s failure to disclose its role in funding high impact research on the topic.^{27 28} Furthermore, Schillinger et al found that studies with links to the sugar sweetened drink industry were more likely than independently funded studies to report no association between sugary drinks (eg, soda, juice) and obesity and diabetes related outcomes.²⁹ Multiple systematic reviews and meta-analyses have also documented the influence of pharmaceutical company funding on the results of clinical trials: Bekelman et al found that industry funding greatly increased the chances of pro-industry results (odds ratio 3.60, 95% confidence interval 2.63 to 4.91), with similar findings reported by Lexchin et al (odds ratio 4.05, 2.98 to 5.51).^{25 30}

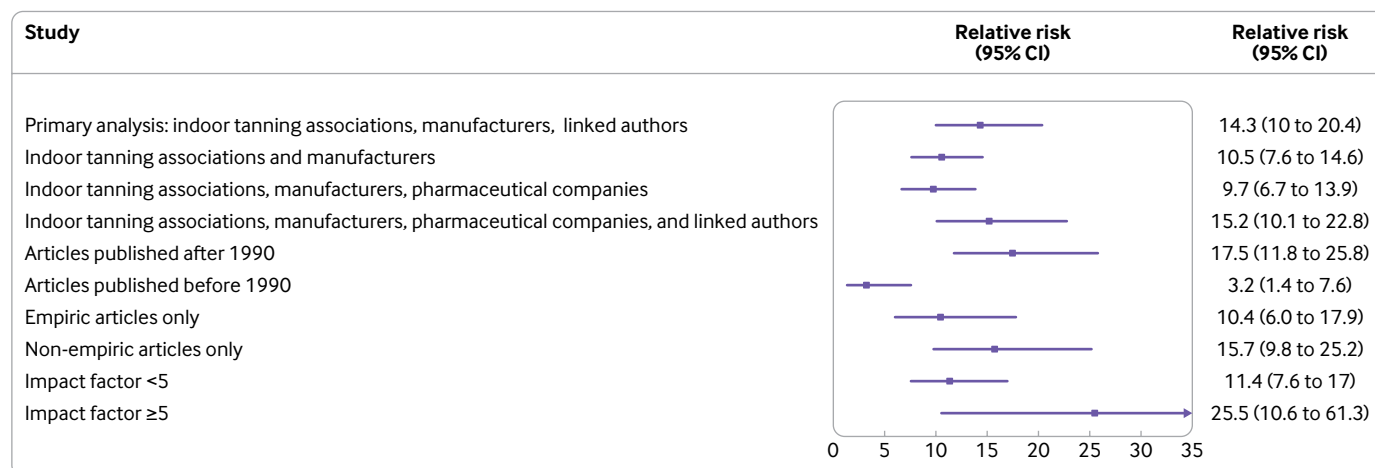


Fig 4 | Forest plot including primary, secondary, and sensitivity analyses. Relative risks of industry funded paper being in favor of tanning (relative to non-industry funded paper) with 95% confidence intervals

Our study provides preliminary evidence that conflicts of interest may be associated with different conclusions in the indoor tanning literature. The number of articles with financial links to the indoor tanning industry is relatively small, so they may have a limited effect on the public dialogue on this subject. However, these few studies may be amplified if cited repeatedly in marketing materials and legal discussions related to the tanning industry. Several studies examining the motivations for indoor tanning have documented that tanners perceive indoor tanning to have real health benefits, suggesting that these messages may be influential.^{6 31} Several benefits of indoor tanning documented in our analysis, including higher concentrations of vitamin D, photoprotection, also referred as a “base tan,” and phototherapy for medical conditions, are also reported in surveys of current tanners’ attitudes, beliefs, and health based motivations about indoor tanning.^{6 32} Additionally, Wehner et al assessed the frequency of indoor tanning and health risks mentioned on Twitter over a two week period and found that only 2.6% of indoor tanning tweets mentioned skin cancer.³³ Nevertheless, vitamin D deficiency is a well established risk factor for autoimmune diseases, cancer, and cardiovascular disease,⁹⁻¹³ and artificial ultraviolet B, like outdoor sun exposure, can increase serum vitamin D. Therefore, we are not attempting to label articles’ claims as true or false. Instead, we show that a strong association seems to exist between a supportive stance toward indoor tanning and financial links to industry.

Limitations of study

This study has several limitations. Firstly, we were able to assess funding sources only if these were disclosed in the full text of the manuscript or in other manuscripts by the same author, so undisclosed funding sources may not have been captured in this analysis. The literature search was limited to articles available on PubMed, Web of Science, and Embase, so we were unable to include more informal online comments

or rapid responses not cited in these databases. Our analysis was limited to articles in English. Our results may also have been limited by our initial search string, which included terms related to skin cancer (including melanoma, basal cell carcinoma, and skin neoplasm) but no other health risks. However, throughout our analysis it became clear that many articles reference additional health risks of indoor tanning (such as burns and immune suppression). If we had included these health risks in our initial search string, our conclusion would likely have contained an even larger proportion of articles critical of tanning. Therefore, we believe that this did not systematically bias our conclusions and may have led to underestimation of effect sizes. Another potential limitation is that we did not directly count the number of health risks and health benefits per article. Although these codes served to inform each independent reviewer’s score for each article, reviewers also considered other elements (including magnitude of risks and benefits, the degree of certainty ascribed to the causative relation between various risks/benefits and indoor tanning, and the overall conclusions of the authors) in determining their final score. Because we used two independent reviewers and these reviewers were blinded to funding and conflict of interest information, we believe that this is unlikely to systematically bias our conclusions.

Conclusions and policy implications

Our results show that articles financially linked to the indoor tanning industry were more likely to have a conclusion in favor of indoor tanning. Public health practitioners and researchers need to be aware of and account for industry funding when interpreting the evidence related to indoor tanning.

We thank Evans Whitaker, an academic research librarian, for his guidance with the development of the search strings for each database. We also thank both Pamela Ling and Stanton Glantz, professors of medicine at University of California, San Francisco, for their feedback on this manuscript.

Contributors: LA and RC contributed equally to the manuscript. EL, MH, and YH contributed to the study design. LA and RC did the

literature search and data extraction with the help of LM for financial coding. VE and EL resolved disagreements. RC and LA designed the tables, figures, and appendices with input from EL and MH. LA and RC prepared the initial drafts of the manuscript with additional input from LM, MH, YH, MW, MMC, and EL. All authors contributed to the drafts and the final version of the manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. LA and RC had full access to all of the data in the study and had final responsibility for the decision to submit for publication. LA and RC are the guarantors.

Funding: EL is supported by the NIH (grants DP2CA225433 and K24AR075060). MH is supported by an NCI/NIH Re-entry Supplement (grant DP2CA225433-02). MRW was supported by NIAMS/NIH Dermatology Research Training grant T32 AR7465 (PI, Sarah E Millar). MC is supported by the NIH (grant R01AR073001). There was no specific funding for the study.

Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/doi_disclosure.pdf and declare: no support from any organization for the submitted work; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: Institutional review board approval was not required for this study

Data sharing: No additional data available.

Transparency: The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Dissemination to participants and related patient and public communities: The media team at Stanford University will be issuing a press release on official publication of this manuscript, in order for the results of the study to have a broad public outreach.

This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

- Wehner MR, Chren MM, Nameth D, et al. International prevalence of indoor tanning: a systematic review and meta-analysis. *JAMA Dermatol* 2014;150:390-400. doi:10.1001/jamadermatol.2013.6896
- Wehner MR, Shive ML, Chren MM, Han J, Qureshi AA, Linos E. Indoor tanning and non-melanoma skin cancer: systematic review and meta-analysis. *BMJ* 2012;345:e5909. doi:10.1136/bmj.e5909
- Mosher CE, Danoff-Burg S. Indoor tanning, mental health, and substance use among college students: the significance of gender. *J Health Psychol* 2010;15:819-27. doi:10.1177/1359105309357091
- Ashrafioun L, Bonar EE. Tanning addiction and psychopathology: Further evaluation of anxiety disorders and substance abuse. *J Am Acad Dermatol* 2014;70:473-80. doi:10.1016/j.jaad.2013.10.057
- Heckman CJ, Coups EJ, Manne SL. Prevalence and correlates of indoor tanning among US adults. *J Am Acad Dermatol* 2008;58:769-80. doi:10.1016/j.jaad.2008.01.020
- Gambala WC, Fernandez AM, Gassman NR, Tan MCB, Daniel CL. College tanning behaviors, attitudes, beliefs, and intentions: A systematic review of the literature. *Prev Med* 2017;105:77-87. doi:10.1016/j.ypmed.2017.08.029
- McKenzie R, Scragg R, Liley B, et al. Serum 25-hydroxyvitamin-D responses to multiple UV exposures from solarium: inferences for exposure to sunlight. *Photochem Photobiol Sci* 2012;11:1174-85. doi:10.1039/c2pp05403e
- Moan J, Baturaite Z, Juzeniene A, Porojnicu AC. Vitamin D, sun, sunbeds and health. *Public Health Nutr* 2012;15:711-5. doi:10.1017/S1368980011002801
- Maddison PJ, Bacon PA. Vitamin D deficiency, spontaneous fractures, and osteopenia in rheumatoid arthritis. *Br Med J* 1974;4:433-5. doi:10.1136/bmj.4.5942.433
- Linos E, Keiser E, Kanzler M, et al. Sun protective behaviors and vitamin D levels in the US population: NHANES 2003-2006. *Cancer Causes Control* 2012;23:133-40. doi:10.1007/s10552-011-9862-0
- Mayor S. Vitamin D does not reduce cancer or cardiovascular events in healthy adults, trial finds. *BMJ* 2018;363:k4776. doi:10.1136/bmj.k4776
- Vitamin D, cardiovascular disease, and other stories. *BMJ* 2019;366:l4411.
- Zhang Y, Fang F, Tang J, et al. Association between vitamin D supplementation and mortality: systematic review and meta-analysis. *BMJ* 2019;366:l4673. doi:10.1136/bmj.l4673
- Dyer O. \$100m alcohol study is cancelled amid pro-industry "bias". *BMJ* 2018;361:k2689. doi:10.1136/bmj.k2689
- McCarthy M. Conflicts of interest may affect conclusions of systematic reviews of flu drugs, study indicates. *BMJ* 2014;349:g6065. doi:10.1136/bmj.g6065
- Ahn R, Woodbridge A, Abraham A, et al. Financial ties of principal investigators and randomized controlled trial outcomes: cross sectional study. *BMJ* 2017;356:i6770. doi:10.1136/bmj.i6770
- Lexchin J, Bero LA, Djulbegovic B, Clark O. Pharmaceutical industry sponsorship and research outcome and quality: systematic review. *BMJ* 2003;326:1167-70. doi:10.1136/bmj.326.7400.1167
- Mayor S. Industry funded studies are less likely to link sugary drinks to obesity, review finds. *BMJ* 2016;355:i5852. doi:10.1136/bmj.i5852
- Ozieranski P, Rickard E, Mulinari S. Exposing drug industry funding of UK patient organisations. *BMJ* 2019;365:l1806. doi:10.1136/bmj.l1806
- Rasmussen K, Bero L, Redberg R, Gøtzsche PC, Lundh A. Collaboration between academics and industry in clinical trials: cross sectional study of publications and survey of lead academic authors. *BMJ* 2018;363:k3654. doi:10.1136/bmj.k3654
- Nguyen KH, Glantz SA, Palmer CN, Schmidt LA. Tobacco industry involvement in children's sugary drinks market. *BMJ* 2019;364:l736. doi:10.1136/bmj.l736
- Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* 2009;339:b2535. doi:10.1136/bmj.b2535
- Hendlin YH, Vora M, Elias J, Ling PM. Financial Conflicts of Interest and Stance on Tobacco Harm Reduction: A Systematic Review. *Am J Public Health* 2019;109:e1-8. doi:10.2105/AJPH.2019.305106
- Lo B, Field M, eds. *Conflict of Interest in Medical Research, Education, and Practice*. National Academies Press, 2009.
- Bekelman JE, Li Y, Gross CP. Scope and impact of financial conflicts of interest in biomedical research: a systematic review. *JAMA* 2003;289:454-65. doi:10.1001/jama.289.4.454
- Barnes DE, Bero LA. Why review articles on the health effects of passive smoking reach different conclusions. *JAMA* 1998;279:1566-70. doi:10.1001/jama.279.19.1566
- Kearns CE, Schmidt LA, Glantz SA. Sugar Industry and Coronary Heart Disease Research: A Historical Analysis of Internal Industry Documents. *JAMA Intern Med* 2016;176:1680-5. doi:10.1001/jamainternmed.2016.5394
- Kearns C, Schmidt L, Apollonio D, Glantz S. The sugar industry's influence on policy. *Science* 2018;360:501.
- Schillinger D, Tran J, Mangurian C, Kearns C. Do Sugar-Sweetened Beverages Cause Obesity and Diabetes? Industry and the Manufacture of Scientific Controversy. *Ann Intern Med* 2016;165:895-7. doi:10.7326/L16-0534
- Lexchin J, Bero LA, Djulbegovic B, Clark O. Pharmaceutical industry sponsorship and research outcome and quality: systematic review. *BMJ* 2003;326:1167-70. doi:10.1136/bmj.326.7400.1167
- Dixon HG, Warne CD, Scully ML, Wakefield MA, Dobbinson SJ. Does the portrayal of tanning in Australian women's magazines relate to real women's tanning beliefs and behavior? *Health Educ Behav* 2011;38:132-42. doi:10.1177/1090198110369057
- Neenan A, Lea CS, Lesesky EB. Reasons for tanning bed use: a survey of community college students in North Carolina. *N C Med J* 2012;73:89-92.
- Wehner MR, Chren MM, Shive ML, et al. Twitter: an opportunity for public health campaigns. *Lancet* 2014;384:131-2. doi:10.1016/S0140-6736(14)61161-2

Web appendix: Appendix 1

Web appendix: Appendix 2

Web appendix: Appendix 3