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Dangerous exposures to chemicals managed by Poison Centers all around the world during the COVID-19 pandemic: a systematic review and proportional meta-analysis

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Abstract

Introduction. During COVID-19 pandemic, cleaning/disinfection activities were highly recommended. This study summarizes the state of art and estimates the prevalence of dangerous exposures to specific chemicals managed by Poison Centers (PCs) from all over the world during 2020 *vs* 2019, trying to overcome the critical aspects of the product categorization systems used by PCs.

Materials and methods. A systematic research was conducted in 3 major databases and 2 websites of PCs associations. Proportional meta-analyses were performed to estimate the prevalence of exposures to disinfectants, household products and hand sanitizers in 2020 *vs* 2019.

Results. The pooled prevalence of exposures to disinfectants, household products and hand sanitizers were respectively 5.9% (95% CI 4.9-7.0) (2019: 4.4% *vs* 2020: 7.8%; p=0.22), 25.9% (95% CI 24.0-27.7) (2019: 25.0% *vs* 2020: 28.6%; p=0.71) and 1.6% (95% CI 1.3-1.9) (2019: 0.6% *vs* 2020: 2.8%; p<0.001).

Conclusions. This study detected overall increases of exposures to specific chemicals in 2020, suggesting that the awareness on topics related to the safe use of these products should be improved, especially during health emergencies, highlighting the need to develop standardized systems to better compare data coming from PCs all over the world.

Key words

- Poison Control Centers
- COVID-19
- disinfectants
- hand sanitizers
- household products

INTRODUCTION

On 2020, the whole world became aware of the COVID-19 health emergency, declared by WHO as a pandemic on 11 March 2020 (https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020). To fight the virus transmission, worldwide Health Authorities (e.g., WHO, CDC) issued a series of guidelines such as: physical distancing and/or strong restrictive measures (lockdown), use of face masks, adequate ventilation of indoor places, environmental cleaning and disinfection (e.g., using products containing sodium hypochlorite, ethanol, or hydrogen peroxide), and a good hand hygiene (e.g., using soap and water or, if soap and water are not available, using hand sanitizers with at least 60% alcohol). All these recommendations have been systematically repeated through the main mass media channels and, riding the wave of fear of such an emergency, have led to an uncontrolled and sometimes unaware use of cleaning and disinfection products [1]. As of today, several studies published by Poison Centers (PCs) from all over the world on this feature can be found in literature, varying a lot from each other in terms of PC characteristics (e.g., catchment area), lockdown periods, variables reported, and product categorization systems used.

The aim of this study is to summarize the state of art of dangerous exposures to specific Chemicals man-

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aged by PCs during the first year of COVID-19 pandemic and to estimate their prevalence in 2020 *vs* the same period of 2019, to understand the global phenomena and to identify possible evidence-based preventive strategies. This study also tries to overcome the critical aspects of the product categorization systems used by PCs, which may lead to inhomogeneous categorizations, by providing three main product categories: disinfectants, household products and hand sanitizers. All data used to estimate the prevalence (2020 *vs* 2019) were extracted by articles during the review process.

MATERIALS AND METHODS

This review was conducted according to a predefined protocol registered on PROSPERO (CRD42023389781) and it is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [2].

Search and selection process

To be included in this review, studies had to:

- be based on data coming from PCs all over the world;
- describe dangerous exposures to specific chemicals (ascribable to disinfectants and/or household products and/or hand sanitizers) occurred in 2020 – whole year or fractions – *vs* the same period of 2019;
- include all subjects exposed to disinfectants and/or household products and/or hand sanitizers;
- be published in English;
- be published from January 2020 to August 2023;
- provide the sufficient numerical data to estimate the prevalence, i.e. each study must provide the exact information on the number of calls per each product category (numerator) divided by the total number of calls received (denominator).

The decision to include studies specifically based on PCs data is motivated by the fact that PCs databases usually assess similar variables. To conduct this study an electronic search was made on PubMed, Web of Science, Google Scholar, the European Association of Poisons Centers and Clinical Toxicologists (EAPCCT) website and the American Association of Poison Control Centers (AAPCC) NPDS website. The following filters were applied: language "English", publication date "2020/01/01 - 2023/08/31", type of work "Publications".

Key words for article searches were: poison center/centre, poison control center/centre, COVID-19 exposures, disinfectants, hand, sanitizer, household product, cleaner. A comprehensive list of studies was created by one researcher and duplicates were removed. A screening based on Title and Abstract according to the inclusion and exclusion criteria was conducted by two researchers. In the eligibility step, all articles were evaluated through a full reading of the text.

The selection process was conducted and reviewed by two researchers.

Quality appraisal

All thirteen articles included in this review [3-15] are descriptive studies on subjects with a known exposure over a period of time. To assess the quality of the articles included, the JBI critical appraisal tool for assessing the quality of case series studies was used [16]. This scale provides 10 questions by which each study is judged *(Table 1)*. The possible answers are "Yes", "No", "Unclear", "Not Applicable". Any "No" response negatively affects the overall quality of the study.

The assessment of the methodological quality per each study is reported in *Table 1*. This step was conducted by one researcher and reviewed by two researchers.

Data collection

Data from all studies were exported to Microsoft® Excel by one researcher and reviewed by a second researcher. Data were extracted to assess the following variables: article, authors, journal, country, period of exposure (Period), total calls received (Total calls), calls disinfectants, calls hand sanitizers, calls household products. The characteristics of all studies included in this review are described in *Table 2*.

With reference to chemicals exposures, the categorization system used to identify products can vary between each PC, leading to a possible heterogeneity among categories (e.g., some products can be considered borderline between disinfectants/cleaners/medical devices/cosmetics).

At EU level, the European Product Categorization System (EuPCS) has been proposed by the European Chemical Agency (ECHA). The EuPCS is a system finalised by ECHA to support industries in submitting information on a mixture they put on the market and to assist the statistical analyses of related poisoning cases (Art. 45 of Reg. (EC) No. 1272/2008 (CLP) [17]). As stated on European Chemical Agency's (ECHA) Poison Centers website, the EuPCS is used to describe 'the intended use of a mixture' for which a submission must be made according to Article 45 and Annex VIII of the CLP Regulation (https://poisoncentres.echa.europa.eu/it/eu-product-categorisation-system). A first version of the EuPCS was published on 20 March 2018 on ECHA's Poison Centers website. As of today, the last version is the 4.0 published in February 2023.

A clear advantage of this tool is the product assignment according to the intended use, which is certainly easier to identify in comparison with other categorizations based, for example, on chemical structures or antimicrobial activities. Furthermore, some product categories driven by specific regulations (e.g., Reg. (EU) No. 528/2012 for biocidal products [18], Reg. (EC) No. 1107/2009 for plant protection products [19]) maintain their original categorization in the EuPCS, so that a full transferability is guaranteed. Moreover, this harmonized system could allow a comparison between statistical analyses of poisoning incidents at EU level, also helping to identify the need for new risk management measures.

Doubtlessly, this system presents limitations as well. Despite its accuracy, ambiguous categorizations are still possible. Moreover, all potentially toxic agents not covered by CLP Regulation (e.g., cosmetics, animals, plants, food, drugs, tobacco) are not included.

Although this system seems to be useful and to bring advantages, it is not currently used by all EU authors in-

Table 1
Methodological quality assessment according to JBI tool

Article	Clear inclusion criteria	Standard and reliable condition measurement	Valid methods to identify condition	Consecutive inclusion of participants	Complete inclusion of participants	Clear reporting of participants' demographics	Clear reporting of clinical information	Outcome results clearly reported	Clear reporting of presenting sites'/ clinics' demographic information	Appropriate statistical analysis
Soave PM *et al.*, 2021 [3]	Yes	Yes	Yes	Yes	Yes	No	NA	Yes	Yes	Yes
Mahmoud NF *et al.*, 2021 [4]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Le Roux G *et al.*, 2021 [5]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Du Plessis CE *et al.*, 2022 [6]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Babić Z *et al.*, 2020 [7]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Giordano F *et al.*, 2022 [8]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Raffee L *et al.*, 2021 [9]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Crescioli G *et al.*, 2022 [10]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Gummin DD *et al.*, 2020 [11]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Gummin DD *et al.*, 2021 [12]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Milella MS *et al.*, 2021 [13]	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
Casey P, Duggan E, 2021 [14]	Yes	Yes	Yes	Yes	Yes	No	NA	Yes	Yes	Yes
Vandijck D *et al.*, 2022 [15]	Yes	Yes	Yes	Yes	Yes	No	NA	Yes	Yes	Yes

NA = Not applicable

cluded in the study: among eight EU studies included in this work, only one specifically refers to the EuPCS [8].

Categorization criteria reported by authors and the related categorization assigned in this review are summarized in *Table 3*.

The three product categories used in this review were conceived as follows:

- *Disinfectants.* All biocidal products included in the Main Group of Disinfectants of Reg. 528/2012 [18] or included in the EuPCS categories from PP-BIO-1 to PP-BIO-5 (same categories). According to Reg. (EU) No. 528/2012, a "biocidal product" is "any substance or mixture, in the form in which it is supplied to the user, consisting of, containing or generating one or more active substances, with the intention of destroying, deterring, rendering harmless, preventing the action of, or otherwise exerting a controlling effect on, any harmful organism by any means other than mere physical or mechanical action; any substance or mixture, generated from substances or mixtures which do not themselves fall under the first indent, to be used with the intention of destroying, deterring, rendering harmless, preventing the action of, or otherwise exerting a controlling effect on, any harmful organism by any means other than mere physical or mechanical action". The definition of "disinfectants" excludes cleaning products that are not intended to have a biocidal effect, including washing liquids, powders, and similar products. All products named "disinfectants" without any other detail allowing to better identify the categorization are included in this category.
- *Household products.* Cleaners according to the definition of Reg. (EC) No. 648/2004 on detergents (the Regulation is now under revision according to the European Commission proposal of April 28th, 2023 [21]): "any substance or preparation containing soaps and/or other surfactants intended for washing and cleaning processes. Detergents may be in any form (liquid, powder, paste, bar, cake, moulded piece, shape, etc.) and marketed for or used in household, or institutional or industrial purposes. Other products to be considered as detergents are:
  - "Auxiliary washing preparation", intended for soaking (pre-washing), rinsing or bleaching clothes, household linen, etc.;
  - "Laundry fabric-softener", intended to modify the feel of fabrics in processes which are to complement the washing of fabrics;
  - "Cleaning preparation", intended for domestic all purposes cleaners and/or other cleaning of surfaces (e.g.: materials, products, machinery, mechanical appliances, means of transport and associated equipment, instruments, apparatus, etc.);
  - "Other cleaning and washing preparations", intended for any other washing and cleaning processes."

Table 2
Characteristics of included studies

Article	Country	Journal	Period 2020 vs 2019	Total calls		Calls disinfectants		Calls hand sanitizers		Calls household products	
				2019	2020	2019	2020	2019	2020	2019	2020
Soave PM *et al.*, 2021 [3]	Italy	Eur Rev Med Pharmacol Sci	30/01 18/05	1,862	1,972	160	250	22	50	-	-
Mahmoud NF *et al.*, 2021 [4]	Saudi Arabia	International Journal of Toxicology	01/01 30/06	2,300	2,431	215	496	10	83	-	-
Le Roux G *et al.*, 2021 [5]	France	Clinical Toxicology	01/03 30/04	30,488	32,182	1,535	2,860	257	870	4,840	5,513
Du Plessis CE *et al.*, 2022 [6]	South Africa	SAJID	01/03 31/08	5,508	5,137	262	274	6	156	1,268	1,280
Babić Z *et al.*, 2020 [7]	Croatia	Arh Hig Rada Toksikol	01/01 30/06	1,165	1,206	26	87	-	-	-	-
Giordano F *et al.*, 2022 [8]	Italy	BMC Public Health	01/03 31/05	2,096	2,526	186	265	6	52	1,007	1,118
Raffee L *et al.*, 2021 [9]	Jordan	BMJ Open	21/03 21/05	285	544	-	-	12	37	32	83
Crescioli G *et al.*, 2022 [10]	Italy	Internal and Emergency Medicine	01/01 30/04	451	410	-	-	-	-	242	267
Gummin DD *et al.*, 2020 [11]	USA	Clinical Toxicology	01/01 31/12	2,148,141	-	12,058	-	2,1729	-	172,344	-
Gummin DD *et al.*, 2021 [12]	USA	Clinical Toxicology	01/01 31/12	-	2,128,198	-	20,010	-	37,460	-	194,950
Milella MS *et al.*, 2021 [13]	Italy	Journal of Medical Toxicology	09/03 31/05	408	366	-	-	-	-	109	131
Casey P, Duggan E, 2021 [14]	Ireland	Clinical Toxicology	01/03 31/07	4,844	5,165	-	-	21	130	-	-
Vandijck D *et al.*, 2022 [15]	Belgium	Clinical Toxicology	01/01 31/12	60,668	65,308	728	2,578	-	-	-	-

The act of cleaning is related to the process by which "an undesirable deposit on the surface and/or within the substrate is dislodged from the substrate and brought into a state of solution or dispersion" (UNI EN ISO 862:2006. Surface active agents). All products named "household products", "home cleaning products", "household cleaners", "cleaning substances" without any other detail allowing to better identify the categorization are included in this category.

- *Hand sanitizers.* With the outbreak of COVID-19, the need of alcohol-based hand cleaning/sanitizing products quickly increased. To respond to this increasing demand, not only pharmaceutical companies but also chemical and cosmetic companies massively produced these items. As a result, a huge amount of different hand cleansers/sanitizers in various formulations (e.g., liquid, gel, or foam) appeared on the market, paving the way for ambiguities in terms of Regulation [22]. In fact, when the primary function stated as a claim on products is clearly referred to a biocidal activity (e.g., "kill bacteria/disinfect/proven effective against viruses"), these products can be considered biocides for human hygiene (PT1) [18], thus intending "sanitizer" as a synonym of "disinfectant" (https://www.theregulatorycompany.com/insights-2/insight-hand-sanitiser-cleanser-cosmetic-or-biocide). When the primary function refers to cleaning/cleansing for personal hygiene, these products can be considered cosmetics [23], still containing denatured alcohol and still being used to contrast COVID-19 transmission. In the context of COVID-19 emergency, these items were demanded with urgency, so the shortest way in terms of compliance and market access could have been chosen.
Given the above, the categorization of these products could be strongly different at global level. In order to identify as rigorously as possible all products intended to be used on hands with cleaning/sanitizing purposes, the category of "hand sanitizers" was provided. All products named "hand sanitizers" or "alcohol-based hand sanitizers" without any other detail are included in this category.
When authors reported a clear reference to PT1 Biocides, these products were included in the "disinfectants" category.

Table 3
Categorization criteria of all studies included and related categorization assigned in review

Article	Categorization criteria reported	Categorization assigned in review
Soave PM *et al.*, 2021 [3]	Household disinfectants = Household chemicals classified according to their antimicrobial properties (including hand sanitizers)	Disinfectants = household disinfectants (excluding hand sanitizers) Hand sanitizers = extracted from the total of "household disinfectants"
Mahmoud NF *et al.*, 2021 [4]	Disinfectants = surface disinfectants Hand sanitizers	Disinfectants Hand sanitizers
Le Roux G *et al.*, 2021 [5]	Home cleaning products = -not containing biocides -containing bleach -containing other biocides than bleach Alcohol-based hand sanitizers	Disinfectants = home cleaning products containing all biocides (bleach and other) Household products = home cleaning products not containing biocides Hand sanitizers = alcohol-based hand sanitizers
Du Plessis CE *et al.*, 2022 [6]	Antiseptic and disinfectants = environmental disinfectants + skin or wound antiseptics (including hand sanitizers) and unknown antiseptics Household chemicals = including cosmetics, household products and handyman products	Disinfectants = environmental disinfectants + skin or wound antiseptics (excluding hand sanitizers) and unknown antiseptics Household products = household chemicals Hand sanitizers = extracted from the total of "skin or wound antiseptics"
Babić Z *et al.*, 2020 [7]	Surface disinfectants = PT2 Reg. (EU) No. 528/2012 Hand sanitizers = PT1 Reg. (EU) No. 528/2012	Disinfectants = surface disinfectants (PT2) + hand sanitizers (PT1)
Giordano F *et al.*, 2022 [8]	Disinfectants = EuPCS categories from PP-BIO-1 to PP-BIO-5 Cleaning, care, and maintenance products (excludes biocidal products) = EuPCS categories PC-CLN Detergents and auxiliaries for laundry and dishwashing (excludes biocidal products) = EuPCS category PC-DET Handwashing gel products (excludes biocidal products)	Disinfectants Household products = EuPCS categories PC-CLN + PC-DET Hand sanitizers = handwashing gel products (excludes biocidal products)
Raffee L *et al.*, 2021 [9]	Household cleaners = products containing ammonia, hydrochloric acid, sodium hypochlorite or alkaline cleaning products, drain and oven cleaners, etc. Alcohol = ethanol-based cleaning solutions, hand sanitizers or pure ethanol as spray (not for intake).	Household products = household cleaners Hand sanitizers = alcohol (the exact number of hand sanitizers could not be extracted)
Crescioli G *et al.*, 2022 [10]	Toxic agents = sanitizer/cleaners, acids/caustic sodas, bleaches, machine detergents, hand washing detergents, other home cleaning products	Household products = toxic agents
Gummin DD *et al.*, 2020 [11]	Cleaning substances (household) = including disinfectants Hand sanitizers = ethanol based, isopropanol based, non-alcohol based, unknown - considered as a subgroup of cosmetics	Disinfectants = extracted from the total of cleaning substances Household products = cleaning substances (excluding disinfectants) Hand sanitizers
Gummin DD *et al.*, 2021 [12]	Cleaning substances (household) = including disinfectants Hand sanitizers = ethanol based, isopropanol based, non-alcohol based, unknown - considered as a subgroup of Cosmetics	Disinfectants = extracted from the total of cleaning substances Household products = cleaning substances (excluding disinfectants) Hand sanitizers
Milella MS *et al.*, 2021 [13]	Household and cleaning products	Household products
Casey P, Duggan E, 2021 [14]	AHS = Alcohol-based hand sanitizers	Hand sanitizers
Vandijck D *et al.*, 2022 [15]	Type 1 biocides (PT1 according to Reg. (EU) No. 528/2012) = human hygiene products including alcohol-based hand sanitizers Type 2 biocides (PT2 according to Reg. (EU) No. 528/2012) = disinfectants and algaecides not intended for direct application to humans or animals	Disinfectants = type 1 + type 2

Data synthesis

Three proportional meta-analyses were conducted to estimate the prevalence of exposures to disinfectants, household products and hand sanitizers reported by PCs during a specific period of 2020 *vs* the same period of 2019 (*Table 2,* the Period variable refers both to 2020 and 2019). In one study, data of exposures occurred before 2020 were reported as 2018-2019 exposure period [5]. In this case, a mean of the exposure data in 2018-2019 was calculated and used as comparison to 2020.

The results of meta-analyses are presented as pooled point estimates of prevalence with a 95% confidence interval. An I^2 statistic quantifying between-studies heterogeneity was estimated. The "metaprop" routine was conducted in Stata Version 17.

RESULTS

According to the inclusion and exclusion criteria and given the results obtained by the quality appraisal (at least 8/10 positive answers per study), all thirteen articles [3-15] were included to conduct the analyses. A flow diagram of the study selection process is reported in *Figure 1*.

Among all, n. 8 studies contributed to estimate the prevalence of exposures to disinfectants and hand sanitizers and n. 7 studies to household products.

As shown in *Table 3*, the product categories reported in all studies vary a lot from each other. For example, data on disinfectants provided by Du Plessis CE *et al.* [6] is affected by the presence of "wound antiseptics", which could belong to pharmaceutical agents taking into consideration the activity on injured skin. This data could not be extracted from the category "skin or wound antiseptics". Regarding Raffee L *et al.* findings [9], both "household cleaners" and "alcohol" categories could lead to differences in the results: the first category does not include the alcohol-based household products for surfaces, which are instead included in the "alcohol" category, combined with alcohol-based hand sanitizers.

Given the above, a great effort was made to provide categories as comprehensive and rigorous as possible.

For each product category, a sensitivity analysis was conducted excluding the main outlier (disinfectants: Mahmoud NF *et al.* [4]; household products: Crescioli G *et al.* [10]; hand sanitizers: Raffee L *et al.* [9]). The results obtained still confirmed a higher percentage of exposures detected in 2020 for each product category (disinfectants - 2019: 3.8%, 2020: 6.4%; household products - 2019: 20.9%, 2020: 23.3%; hand sanitizers - 2019: 0.6%, 2020: 2.5%).

Considering the small sample (less than 10 studies included per each analysis), the publication bias was not formally assessed according to the recommendations of the *Cochrane Handbook* [24].

Disinfectants

Soave PM *et al.* [3], Mahmoud NF *et al.* [4], Le Roux G *et al.* [5], Du Plessis CE *et al.* [6], Babić Ž *et al.* [7],

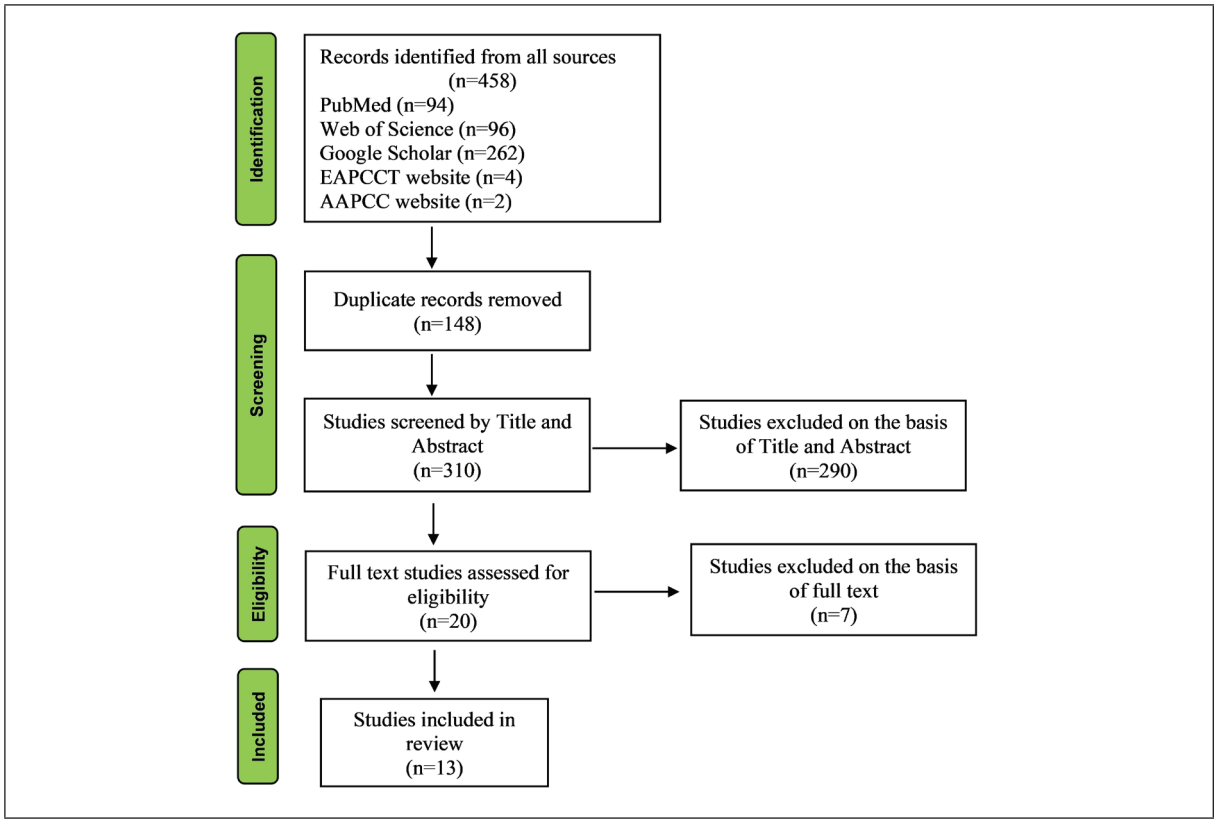

Figure 1
Study selection process flow diagram.

Giordano F *et al.* [8], Gummin DD *et al.* [11, 12] and Vandijck D *et al.* [15] contributed to estimate this value *(Figure 2)*. An increase of exposures to disinfectants was observed in 2020 (2019: 4.4%; 95% CI 2.5-6.8 *vs* 2020: 7.8%; 95% CI 4.2-12.5), although the value does not reach the statistical significance (p=0.22). Mahmoud NF *et al.* [4] show the highest difference from 2019 to 2020, with an increase of 11 percent point (pp) (2019: 9.4% *vs* 2020: 20.4%). A strong heterogeneity between studies is observed (I^2=99.9%; p<0.0001) *(Figure 2)*.

Household products

For household products exposures, a non-statistically significant increase of 3.6 pp can be pointed out in 2020 (2019: 25.0%; 95% CI 17.1-34.0 *vs* 2020: 28.6%; 95% CI 20.4-37.6; p=0.71) by analyzing data of Le Roux G *et al.* [5], Du Plessis CE *et al.* [6], Giordano F *et al.* [8], Raffee L *et al.* [9], Crescioli G *et al.* [10], Gummin DD *et al.* [11, 12], Milella MS *et al.* [13] (*Figure 3)*. Prevalence values for 2019 and 2020 vary a lot from each other, shifting from values under 10% in 2019 and 2020 (Gummin DD *et al.* [11, 12]) to values over 50% in 2019 and 2020 (Crescioli G *et al.* [10]).

The I^2 statistics of 99.9% (p<0.0001) *(Figure 3)* indicates strong heterogeneity between studies.

Hand sanitizers

The prevalence of exposures to hand sanitizers was estimated by analyzing data of Soave PM, *et al.* [3], Mahmoud NF *et al.* [4], Le Roux G *et al.* [5], Du Plessis CE *et al.* [6], Giordano F *et al.* [8], Raffee L *et al.* [9], Gummin DD *et al.* [11, 12], Casey P, Duggan E [14] *(Figure 4),* observing a statistically significant increase of 2.2 pp in 2020 (2019: 0.6%; 95% CI 0.4-0.9 *vs* 2020: 2.8%; 95% CI 2.2-3.5; p<0.001). The results obtained in 2019 and in 2020 seem to be generally similar across studies, except for Raffee L *et al.* [9] (2019: 4.2% *vs* 2020: 6.8%). The I^2 statistics of 99.7% (p<0.0001) *(Figure 4)* indicates strong heterogeneity between studies.

DISCUSSION

To our knowledge, this is the first meta-analysis based on PCs data from all over the world with the aim of estimating the prevalence of dangerous exposures possibly related to COVID-19 pandemic by providing three main product categories (disinfectants, household products and hand sanitizers) as inclusive and precise as possible.

An increase of exposures to the three product categories in 2020 was detected, though reaching the statistical significance only for hand sanitizers (p<0.001). Some studies show higher prevalence with respect to others (e.g., disinfectants: Mahmoud NF *et al.* [4]; household products: Giordano F *et al.* [8], Crescioli G *et al.* [10]; hand sanitizers: Raffee L *et al.* [9]). This evidence is mainly explained by the different categorization system used, based either on active ingredients, antimicrobial

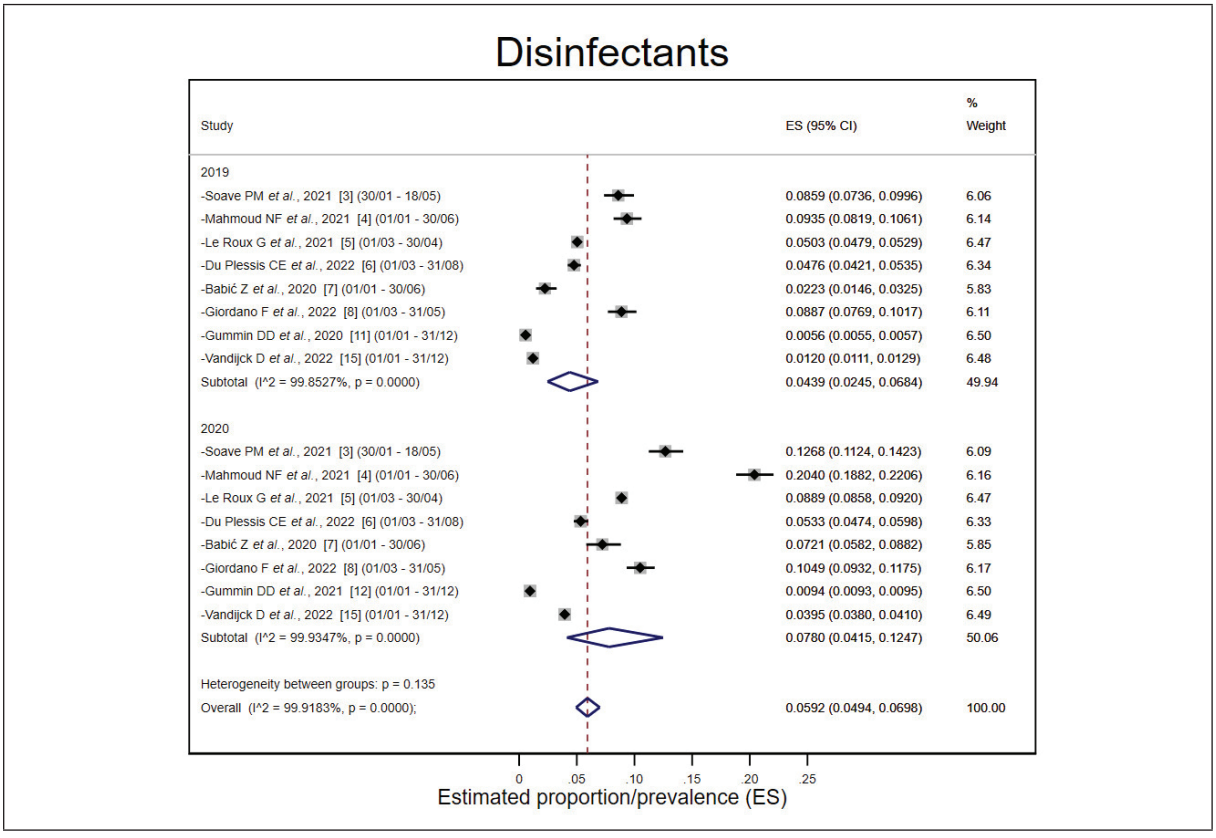

Figure 2
Prevalence of exposures to Disinfectants (2020 *vs* 2019).

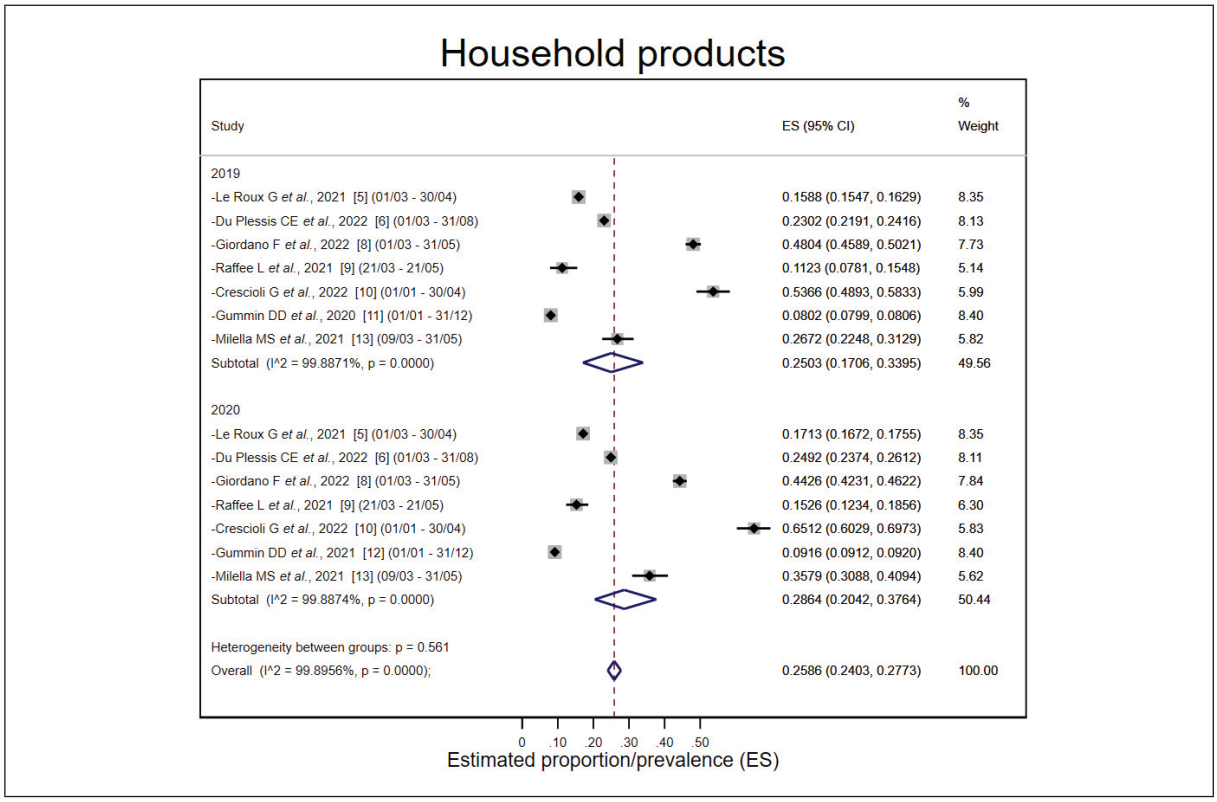

Figure 3
Prevalence of exposures to Household products (2020 *vs* 2019).

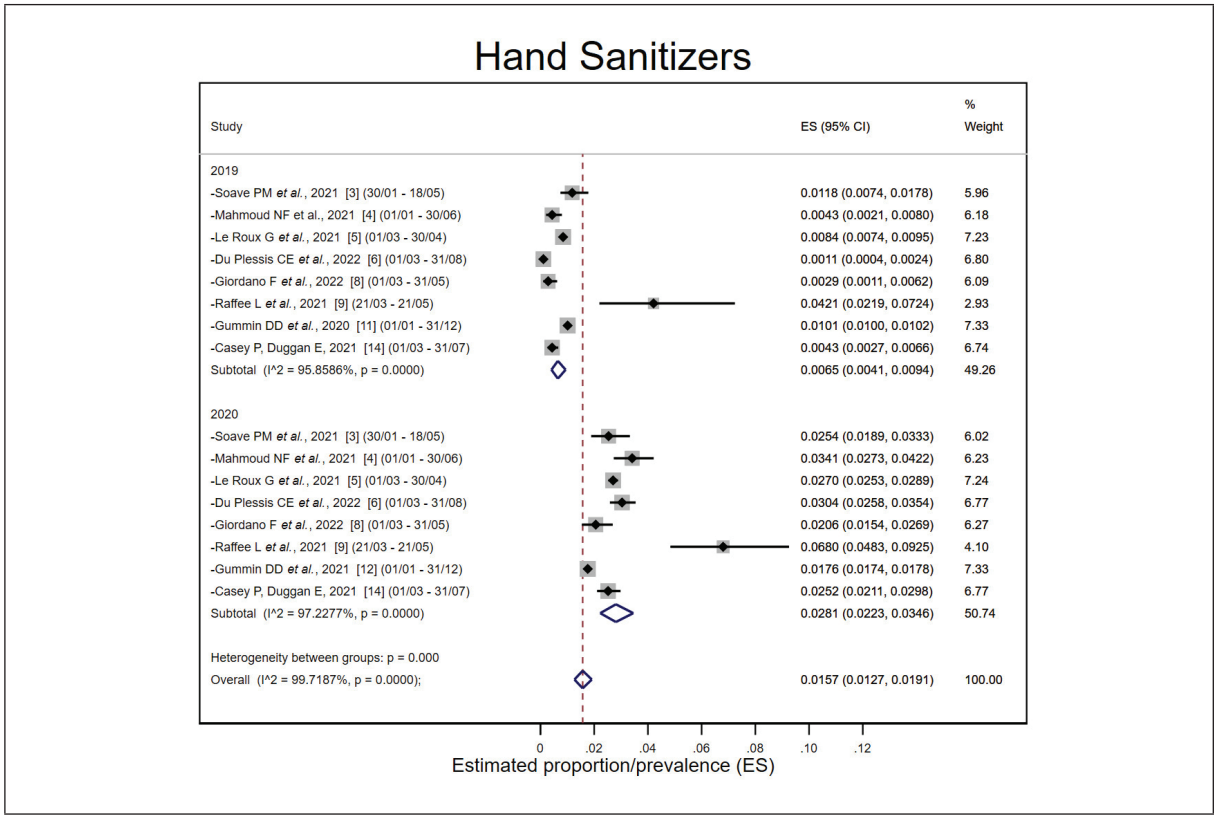

Figure 4
Prevalence of exposures to Hand Sanitizers (2020 *vs* 2019).

properties and/or on the main intended use of a mixture, leading to a possible overestimation of some values.

Despite PCs differences, comprehensive studies starting to appear in literature proved that COVID-19 strongly changed calls volume and characteristics managed in 2020 [25]. The fear of such an unexpected health emergency doubtlessly promoted wrong behaviors, posing health at risk [26]. On May 2020, an opt-in Internet panel survey aimed at characterizing knowledge and practices regarding household cleaning and disinfection during COVID-19 pandemic was conducted by Radhika Gharpure *et al.* [27]. This survey involved 502 US adults and highlighted knowledge gaps in several areas, such as: safe preparation of cleaning and disinfectant solutions, use of recommended Personal Protective Equipment (PPE), safe storage of hand sanitizers, cleaners, and disinfectants. The 39% of respondents reported to have implemented at least one of non-recommended high-risk practices with the intent of preventing SARS-CoV-2 transmission. All these practices, like washing food products with bleach, applying household cleaning or disinfectant products to bare skin and intentionally inhaling or ingesting these products, seriously pose health at risk and must be avoided. Analyzing data coming from the NPDS, Chang *et al.* [1] found that, among all cleaner products, bleaches accounted for the largest percentage of the increase detected in 2020. The American study also describes a case report of a woman who mixed a 10% bleach solution, vinegar, and hot water to wash her food. As a result, she immediately noted a "chlorine" smell, she developed difficulty in breathing, coughing, and wheezing and had to be transported to the Emergency Department. Dindarloo *et al.* [28] performed a descriptive-analytical study involving 1,090 participants with the aim of investigating the pattern of disinfectants use within outbreak of COVID-19 and estimating the adverse effects on public health. This study highlighted that around 60% of participants used to mix different kind of substances (e.g., sodium hypochlorite and alcohol with water) at home to create a disinfectant solution. The reaction of these substances could lead to the production of secondary compounds harmful to health. Only 10% of participants declared to follow the right way to mix chemicals, indicating an alarming trend that puts health at risk without even leading to effective solutions. It should be noted that two previous European surveys conducted in 2014 (http://data.europa.eu/88u/dataset/S872_74_3_EBS360) and 2018 [29] already highlighted a lack of knowledge about chemicals, both in correctly identifying the type of chemical in use and in understanding and reading the instructions on labels, that however should report clear and true information. For example, it is known that active ingredients in hand sanitizers are usually ethanol, isopropyl alcohol, and n-propanol, and their bactericidal and virucidal activity mainly depends on the concentration of alcohol [30]. Therefore, the name of the alcohol and its percentage should be correctly declared on labels, to inform consumers and ensure quality, effectiveness, and safety. A survey conducted in Dubai [31] proved that 6 of the 102 tested alcohol-based hand sanitizers contained undeclared methanol (which should be avoided in such products because of its high toxicity [32]) or a percentage of alcohol lower than 60%, in contrast with the indication given on labels. Moreover, since hand sanitizers are also sold in colorful packaging and seem to have pleasant flavors, children may be attracted to these products and try to lick it [33]. To avoid accidental exposure of unaware children that can lead to adverse effects, hand sanitizers should always be stored safely by adults [34].

CONCLUSIONS

This study confirms that COVID-19 strongly modified lifestyle habits and the exposure profile to specific categories of chemicals all around the world. Considering the diversity of PCs studies, a great effort was made to synthesize data and provide comprehensive results, showing non-statistically significant increases of exposures to disinfectants and household products and a statistically significant increase for hand sanitizers in 2020 at global level. The results obtained suggest the need to better understand how much consumers are aware of benefits and risks related to the use of chemicals and to what extent they know how to protect themselves. This evidence could represent an encouragement for worldwide competent authorities to improve public health by increasing the awareness on specific topics, such as: safe use of chemicals (right and wrong behaviors), how to read and interpret labels, what a PPE is and how to use it, the necessity of keeping chemicals out of the reach of children. This work also highlights the need to develop standardized systems with the aim of comparing data from PCs all over the world and allowing reliable epidemiological comparison.

COVID-19 emergency has certainly increased the attention towards the scientific community. Therefore, this could represent a precious opportunity for Institutions to establish even more fruitful dialogues with the general population, aiming at understanding difficulties and needs of citizens and providing increasingly clear and reliable answers on public health related issues.

Limitations of the study and further improvements

This work surely presents some limitations. First, the heterogeneity between studies in terms of sample sizes, variables reported, different period of interest and different categorization systems. The lockdown period due to COVID-19 was not always similar among countries, so a consistent variability of the exposure data can be observed. It should be also noted that the profile exposure to specific product categories could be affected by seasonality.

Doubtlessly, some improvements could be proposed in future. The Authors could be asked for more accurate data to refine the analyses reported and to include additional studies. A greater knowledge of the categorization criteria used in each study could lead to more precise analyses.

Authors' contributions

LL, FG, and RD worked on the study design. LL performed the identification of studies. LL and PMD conducted the screening and eligibility step. LL con-

ducted the quality analysis. LL, PMD and FG reviewed the selection and quality-check process. PMD organized the dataset to conduct the statistical analysis and performed the meta-analysis with the contribution of LL. LL and PMD worked on the results. LL and FG worked on the discussion, limitations, and conclusion with the contribution of FRM, FC, LR and FM. All authors made edits and contributions to the final draft. The Authors read and approved the final manuscript.

Conflict of interest statement

The Authors declare they have no competing interests.

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