

ORIGINAL ARTICLE

SARS-CoV-2 prevalence and transmission in swimming activities: Results from a retrospective cohort study

Martin Brink Termansen¹  | Ask Vest Christiansen²  | Sebastian Frische¹ 

¹Department of Biomedicine, Aarhus University, Aarhus, Denmark

²Department of Public Health, Aarhus University, Aarhus, Denmark

Correspondence

Sebastian Frische, Department of Biomedicine, Aarhus University, Aarhus, Denmark.
Email: sfri@biomed.au.dk

There is an urgent need for research on the epidemiology of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing coronavirus disease 2019 (COVID-19), as the transmissibility differs between settings and populations. Here we report on a questionnaire-based retrospective cohort study of the prevalence and transmission of SARS-CoV-2 among participants in swimming activities in Denmark in the last 5 months of 2020 during the COVID-19 pandemic.

Eight of 162 swimming activities with a SARS-CoV-2 positive participant led to transmission to 23 other participants. Overall, the percentage of episodes leading to transmission was 4.9% (competitive swimming 8.9%; recreational swimming 1.3%). Overall, the incidence rate of transmission was 19.5 participants per 100 000 pool activity hours (corresponding values: 43.5 and 4.7 for competitive and recreational swimming, respectively).

Compliance with precautionary restrictions was highest regarding hand hygiene (98.1%) and lowest in distancing personal sports bags (69.9%). As a result of low statistical power, the study showed no significant effect of restrictions.

Insight into the risk of transmission of SARS-CoV-2 during indoor swimming is needed to estimate the efficiency of restrictive measures on this and other sports and leisure activities. Only when we know how the virus spreads through various settings, optimal strategies to handle the COVID-19 pandemic can be developed.

KEYWORDS

COVID-19, epidemiology, questionnaire, recreational water, restrictions, sports, survey, swimming pool

1 | INTRODUCTION

Coronavirus disease 2019 (COVID-19) has since its outbreak in December 2019 caused millions of deaths worldwide and is declared a pandemic by the World Health Organization.¹ Since it arrived in Denmark in February 2020, within the first year 212 339 persons were tested positive of the disease (3.7% of the population), leading to 2359 deaths.² COVID-19 is caused by the newly emerged severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; family *Coronaviridae*, genus *Betacoronavirus*).^{3,4}

SARS-CoV-2 is recognized to be transmitted primarily by droplets and close contact, secondarily by fomites and aerosols, and possibly fecal-oral, mother-to-child and bloodborne transmission.⁵

To limit the spread of SARS-CoV-2, the Danish Government mandated an extensive lockdown of the Danish society on March 11, 2020.⁶ On June 8, 2020, indoor sports activities were reopened but subjected to restrictive measures.⁷ As regards indoor water sports “Corona Restrictions in Water Sports” (“Vandsportens Coronaregler”) was published by the Danish Swimming

Federation (DSF) with guidance from the Danish health authorities.⁸ The restrictions involved among other things: thorough sanitation and showering; limiting physical activity around the pool area; limiting group size to maximum 50 participants, though still allowing multiple groups in the same facility and in the same pool; and distancing between and within groups in and out of the water. Simultaneously, the Danish Environmental Protection Agency advised an increase in swimming pool free chlorine contents to at least 0.8 mg/L.⁹

Because of limited knowledge and an unpredictable behavior of coronavirus, the extent of transmission of SARS-CoV-2 in swimming activities compared to other sports and leisure activities is still debated. Indoor swimming has conditions similar to other indoor activities for transmission by droplets and close contact. However, the aquatic environment may affect transmission rates. Evaporation from the water surface necessitates effective pool hall air ventilation, which may also affect the risk of transmission, as strong associations exist between ventilation and airborne transmission of infective diseases.¹⁰

The majority of swimming pool-related disease outbreaks are caused by enteric viruses and by adenoviruses in particular.¹¹ As such, fecal-oral transmission is the most common cause of general viral transmission through swimming pool water. While theoretically possible, fecal-oral transmission of SARS-CoV-2 is currently considered a minor contributor to overall disease spread.^{5,11,12} As virus cannot replicate outside the host's tissue, all SARS-CoV-2 in swimming pool water must result from direct contamination through release of respiratory droplets or body fluids.

Viral transmission in swimming pools is generally related to low concentrations of disinfectants such as chlorine.¹³ High susceptibility to chlorine seems to be applicable to human coronaviruses specifically.¹⁴ Further, enveloped viruses are recognized to be instable in water, although this has been challenged by SARS-CoV-2 because of its particularly hard outer shell.¹⁵ Nevertheless, a recent study demonstrated chlorinated water from British swimming pools (minimum 1.5 mg/L) to effectively reduce SARS-CoV-2 cell infectivity.¹⁶ The implications of these results for everyday practice are uncertain, as water is not considered a primary transmission route. Further, the free chlorine level is in many countries often lower than 1.5 mg/L, for example, when following Danish recommendations of which the lower limit before the pandemic was 0.4 mg/L.⁹ To understand the extent of transmission of SARS-CoV-2 in swimming, observational and experimental studies of real swimming activities are needed. Even so, we are not aware of any such scientific reports of SARS-CoV-2 epidemiology in swimming pools.

To fill this knowledge gap, this study was designed as a retrospective questionnaire-based cohort study to

quantitatively describe the extent of transmission of SARS-CoV-2 at indoor swimming activities in Danish swimming clubs during the last 5 months of 2020. We aimed to measure both the number of risk episodes, where a SARS-CoV-2 positive subject was participating in a swimming activity, and transmission episodes, where other participants in a risk episode subsequently tested positive for SARS-CoV-2. We further aimed to investigate the compliance to and effect of the restrictions on the use of swimming facilities that was in effect in Danish swimming clubs during the study period.

2 | MATERIALS AND METHODS

2.1 | Situational background

From June 8, 2020, until a new lockdown on December 9, 2020, Danish swimming clubs were allowed to resume swimming activities under a set of precautionary restrictions to prevent spread of SARS-CoV-2 virus.^{7,8,17} Overall, the clubs reached close to normal weekly swimming activity levels in the pools as regards the amount of sessions and participants, but the number of competitions were reduced and public access to swimming pools was not allowed.

The Danish public health system provided free access to polymerase chain reaction (PCR) tests for all citizens based on a self-service booking system. Timeslots for tests were normally available within 24 h and results normally available within 48 h after testing.

2.2 | Study design

This is a questionnaire-based, nationwide, retrospective cohort study of swimming activities in Danish swimming clubs in the last 5 months of 2020. Certain analyses include data only from swimming activities in the period August 3, 2020, when most Danish summer holidays had ended, until December 6, 2020, the last week before the new lockdown.^{7,17} In this period (week 32 to week 49) all Danish swimming clubs were allowed full activity.

2.3 | Participants

Geographically, this survey covered all five Danish regions. The sampling frame was DSF's official list of member clubs ($n = 298$). One official contact person from each swimming club was invited by email to participate. As all DSF member clubs were invited, sample size was not calculated beforehand. The exact number of swimming clubs in Denmark is not known, but DSF estimates >75% of

indoor swimming clubs in Denmark to be DSF members. DSF further estimates their member clubs to cover >95% of all Danish club swimmers, comprising both competitive swimming, water polo and recreational swimming. The last category comprises swimming lessons, aqua fitness, water gymnastics, warm water exercise, aquaphobia training, and family swimming among other.

2.4 | Data collection

A questionnaire in Danish language was developed and distributed electronically via SurveyXact (Rambøll Management Consulting, Aarhus, Denmark) on December 17, 2020 (see Supporting Information, Questionnaire 1). Deadline for replies was January 14, 2021. Two emails and in some cases one telephone reminder were given to non-responders in early January 2021. It took 10–30 min to fill in the questionnaire depending on number of reported risk episodes. No validation study of the questionnaire was performed; however, before distribution, all question-and-answer options were piloted for comprehensibility among the research group and other peers and the questionnaire was revised accordingly.

A total of 208 questions were included in the questionnaire, although the number of questions to individual respondents depended on their answers. Questions were multiple choice and open-ended. Multiple choice questions were provided with “I do not know” and “Other” (open-ended) options where appropriate. The questionnaire collected information about the respondent's role in the swimming club, the swimming club and its pool facilities, pool free chlorine level and pool activity hours in different categories of swimming activities. Further, the questionnaire collected the following information on specific risk episodes: category of swimming activity, number of participants, if any other participants subsequently tested positive for SARS-CoV-2, compliance to restrictions, and a free-text field for additional information.

To prevent large swimming clubs with high numbers of risk episodes from not responding because of the time it would take to answer the electronic questionnaire, a manual questionnaire recording similar information but with a less detailed approach was developed (see Supporting Information, Questionnaire 2). In this short version, questions were combined across multiple risk episodes and the respondent was not asked to consider the compliance to every restriction at every risk episode. The concerned swimming clubs were not included in the compliance analysis. During follow-up of non-responders, this questionnaire was used on request.

During analysis, it became clear that the formulation of one question resulted in ambiguous answers. The

question was: “Were all close contacts at the risk episode subsequently tested?” To this, 13 clubs replied “Other” and specified some details, which were evaluated. Data from clubs that instructed participants to be tested according to national guidelines were included for estimation of transmission fraction. Follow-up phone calls were made to 11 swimming clubs who had replied “Do not know” to the question. Based on these phone calls, data were included from clubs who instructed participants to be tested according to national guidelines. Data from clubs answering “No” to the question were excluded and data from clubs answering “Yes” were included.

Some clubs reported risk episodes and transmission episodes not related specifically to indoor swimming activities (other sport activities, training camps etc.). These episodes were not included in the study.

2.5 | Outcome measures

Primary outcome: The fraction of risk episodes that resulted in other participants subsequently testing positive for SARS-CoV-2.

Secondary outcomes: The incidence of SARS-CoV-2 transmission during swimming activities and the relation between precautionary restrictions and SARS-CoV-2 transmission episodes.

2.6 | Data processing and statistical analysis

Data were analyzed using Microsoft Excel v. 16.43 for Mac (Microsoft Corporation, Seattle, WA) and statistical analyses were conducted with Stata/IC v. 16.1 for Mac (StataCorp LCC, College Station, TX). Figures were made using GraphPad Prism version 9.0.2 for Mac (GraphPad Software, San Diego, CA) or Lucidchart (www.lucidchart.com).

We intended to sample proportionally equal during the study period as well as geographically in the five Danish regions and assumed that the number of risk episodes observed overall and within each category of swimming activities would be proportional to the general incidence of SARS-CoV-2 virus in Denmark in the study period.

To test if our sampling was biased in time, we performed a simple linear regression to assess the ability of the weekly SARS-CoV-2 positive cases in Denmark² to predict the weekly number of sampled risk episodes. The model was checked by diagnostic plots of residuals. Further, to test any geographic bias, we compared the regional proportions of all publicly available PCR confirmed SARS-CoV-2 positive cases in Denmark² to the observed

regional proportions of risk episodes. Hypotheses of no difference in proportions were assessed using a Chi-square test of independence with an alpha level of 0.05. Further, we graphically compared weekly regional and national SARS-CoV-2 infection incidence to observed weekly regional and national risk episodes. One hundred twenty six risk episodes for which week numbers were available and that were held in week 32–49 in 2020 (both weeks included) were included in these analyses.

Obviously, the validity of the reported data on risk episodes depended heavily on the extent of the reporting person's knowledge of swimmers' SARS-CoV-2 status. To identify potential risk of bias we assessed the difference in sampling of risk episodes in different swimming activity categories by comparing the number of risk episodes reported from each category per pool activity hours (hours of activity per swimming pool premise in that particular category) using the Poisson model and Fisher's exact test with an alpha level of 0.05.

For incidence rates the period at risk was defined as pool activity hours. Responses from swimming clubs were included if these reported both weekly pool activity hours and week numbers of any potential risk episodes. Swimming clubs only reporting risk episodes, where close contacts were not subsequently asked to be tested, were excluded. Swimming clubs reporting risk episodes both with and without testing of close contacts were included. In total, five reported transmission episodes leading to transmission to 15 other participants were included to estimate incidence rates. The period was limited to week 32–49 in 2020 (both weeks included) for competitive swimming and water polo, and week 35–49 (both weeks included; week 42 excluded) for recreational swimming. The weeks differed because of public holidays affecting recreational swimming activities only. The reported weekly pool activity hours were multiplied according to these periods. No confidence intervals were given, as the Poisson distribution was challenged on independence by transmission to more than one individual at some risk episodes.

To describe the circumstances under which this study was performed, we report descriptive statistics of the level of compliance to nationwide restrictions and number of participants in risk episodes.

The level of compliance to restrictions is reported as a bar chart showing the proportions of risk episodes following restrictions. As the reporting of risk episodes may not be representative of all swimming activities, no confidence intervals are reported for these data. The number of participants in risk episodes is presented as a scatter plot with marking of the mean.

One hundred twelve risk episodes at which close contacts afterward were tested for SARS-CoV-2 by PCR were included in the analysis of effect of the individual restrictions. Effect was measured as risk difference and risk ratio of transmission of SARS-CoV-2. A Fisher's exact test was used to assess the hypothesis of no difference using Bonferroni adjusted alpha levels of 0.005 per test (0.05/10). Estimates were given with 95% confidence intervals and the respective power. The same 112 activities were included in the graphical analysis of the summarized effect of restrictions. We made a bar chart of the number of risk episodes and transmission episodes that followed between 1 and 10 restrictions.

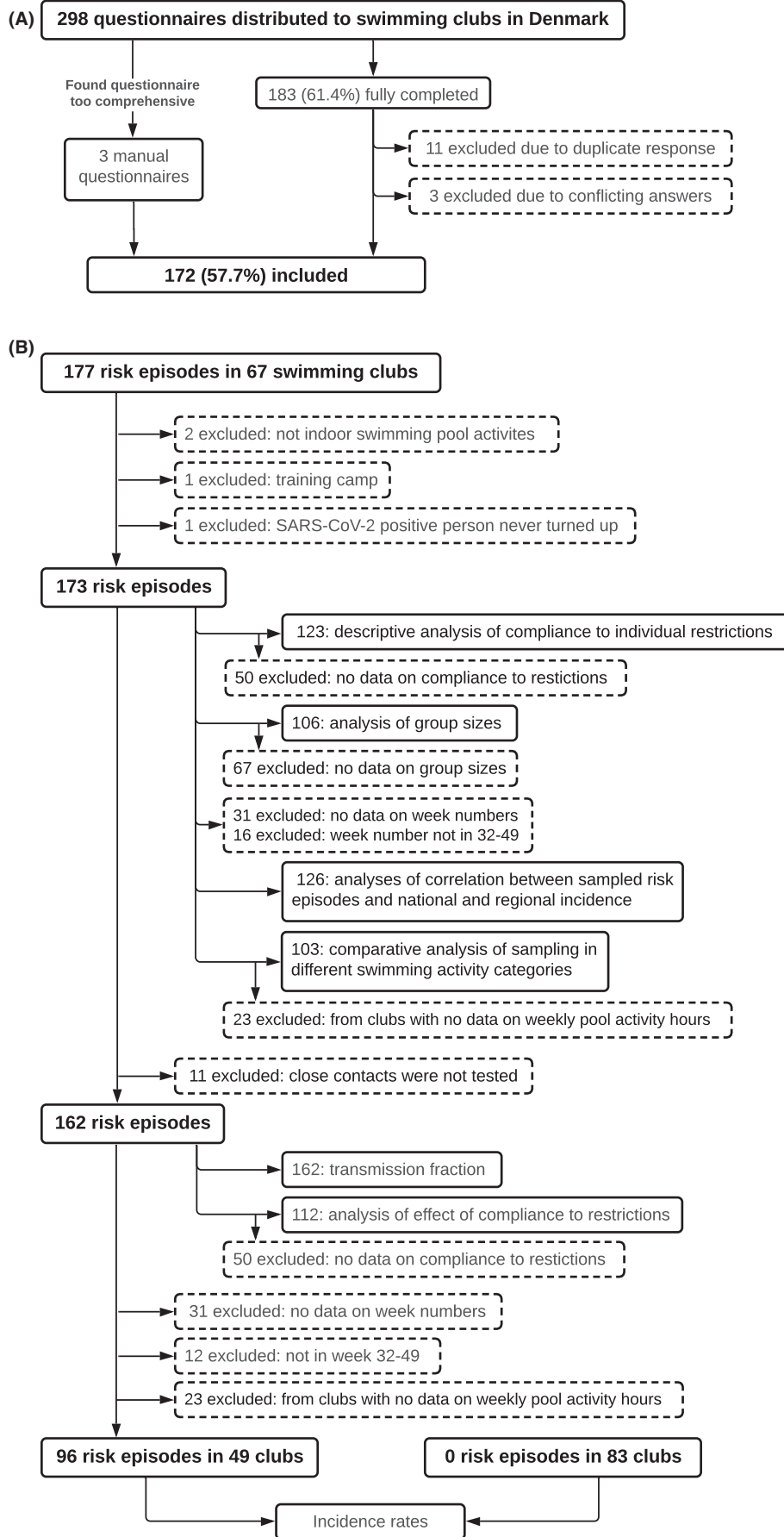
2.7 | Ethics

Informed consent was obtained from all participants (swimming clubs) included in the study. No information obtained could lead to identification of individual swimmers. Aarhus University's Research Ethics Committee (Institutional Review Board) confirmed that the study did not need ethical approval by the Committee.

3 | RESULTS

We received 183 replies to the electronic questionnaire and three replies to the shorter manual questionnaire (Figure 1A). Eleven of these were excluded as duplicates, and three were excluded because of deficient or conflicting answers that could not be corrected despite several email exchanges. This led to inclusion of answers from 172 of the 298 invited swimming clubs (response rate: 57.7%). The sampled swimming clubs had in total 159 807 members, corresponding to 82.7% of all members in DSF

FIGURE 1 Inclusion and exclusion of respondents and answers. (A). Three manual questionnaires were on request sent by email to three larger swimming clubs to obtain a more efficient overview of their many risk episodes (swimming activity where a SARS-CoV-2 positive subject was participating). Three online responses were excluded because of inconsistency such as different answers on number of risk episodes or lack of knowledge on central questions, that is, number of risk episodes. (B). After removal of reported risk episodes not solely associated with indoor swimming activities, 173 risk episodes from 66 swimming clubs were available for the analyses. The remaining 106 swimming clubs reported zero risk episodes. The questionnaire was built to retrieve detailed information on up to four risk episodes (risk episodes above four were followed up by email and phone), and the respondents were always given the opportunity to answer "I do not know." However, all details were not reported for all risk episodes, so only a subset of risk episodes were included in each analysis, for example, only 123 risk episodes reported data on compliance to restrictions. Eleven risk episodes were excluded in primary and secondary outcome analyses as a result of no testing of close contacts



member clubs (data from DSF). The respondents often served multiple roles in the swimming clubs, as 112 of respondents (65.1%) were board members, 55 (32.0%) were leaders, 40 (23.3%) were coaches, 27 (15.7%) were instructors, and 20 (11.6%) were swimmers.

All 172 swimming clubs reported if they had experienced any risk episodes, and whether these had led to transmission of SARS-CoV-2 to other participants. One hundred seventy nine risk episodes were reported in 67 swimming clubs (Figure 1B). Only well-defined indoor swimming activities were included. This led to inclusion of 173 risk episodes in 66 swimming clubs. One hundred sixty two risk episodes in 63 swimming clubs were included in analyses on fractions or risks of transmission, as 11 risk episodes were excluded because of lack of testing of close contacts. None of these 11 risk episodes were reported to lead to transmission of SARS-CoV-2. Complete information could not be obtained on all questions for all risk episodes. Weekly pool activity hours in week 32–49 in 2020 were reported by 132 swimming clubs, all of whom reported week numbers of their potential risk episodes and had all close contacts tested (Table 1).

3.1 | Validity of reported data

On national level, weekly SARS-CoV-2 incidence and number of sampled risk episodes were linearly correlated over time with an R^2 of 0.814 ($F_{1,16} = 69.77, p < 0.001$) (Figure 2). Further, there was no statistically significant difference in regional proportions of SARS-CoV-2 positive cases and regional proportions of risk episodes, $\chi^2(4) = 4.44, p = 0.350$ (Table 2). The weekly distribution of 126 risk episodes to the regional and national incidence is shown in Figure 3.

A higher number of risk episodes per pool activity hours was seen in competitive swimming (153.1 risk

episodes per 100 000 h) compared to recreational swimming (115.4 risk episodes per 100 000 h), although this was not statistically significant ($p = 0.162$). There was no statistically significant difference in rate of risk episodes between water polo (99.9 risk episodes per 100 000 h) and recreational swimming ($p > 0.999$) or water polo and competitive swimming ($p = 0.870$). One hundred three risk episodes in week 32–49 from swimming clubs reporting pool activity hours were included in this analysis.

3.2 | Fraction of risk episodes resulting in transmission

Of 162 total risk episodes eight (fraction: 4.9%) led to transmission to 23 participants (Table 3). In competitive swimming seven of 79 risk episodes (fraction: 8.9%) led to transmission to 21 participants. In recreational swimming one of 79 risk episodes (fraction: 1.3%) led to transmission to two participants. In water polo there was reported no transmission.

3.3 | Incidence rates of SARS-CoV-2 transmission

Overall, swimming activities in the defined period resulted in transmission of SARS-CoV-2 to 19.5 participants per 100 000 pool activity hours.

In competitive swimming, the period at risk for week 32–49 (both weeks included) were estimated to 29 852 pool activity hours. In this period, competitive swimming resulted in transmission of SARS-CoV-2 to 43.5 participants per 100 000 pool activity hours. In recreational swimming, the period at risk for week 35–49 (both weeks included; week 42 excluded) were estimated to 42 932 pool activity hours. In this period, recreational swimming resulted in transmission of SARS-CoV-2 to 4.7 participants per 100 000 pool activity hours. In water polo, the period at risk for week 32–49 (both weeks included) were estimated to 4005 pool activity hours. As no transmission episodes were recorded, no incidence rate for this category was calculated.

3.4 | Compliance to restrictions and their effect

For 123 risk episodes, 61 swimming clubs reported the compliance to each of 10 specific restrictions (Figure S1). The highest compliance was to washing hands upon arrival and at departure from the swimming pool facilities (98.1%). The lowest compliance was to keeping distance between personal bags, equipment etc. (69.9%).

TABLE 1 Weekly pool activity hours in 132 Danish swimming clubs in week 32–49 in 2020

	Total	Competitive swimming	Recreational swimming [§]	Water polo
Pool activity hours [†]	4915 [‡]	1658	3067	223

Note: Responses from 132 swimming clubs, as these reported pool activity hours, reported week numbers of potential risk episodes, and not all risk episodes had no testing of close contacts.

[†]Number of weekly hours the swimming pool facilities were used for this swimming activity category. Rounded to nearest integer.

[‡]As different swimming activity categories may take place simultaneously in the same swimming pool facilities, the total does not sum up the three disciplines.

[§]All swimming activities but competitive swimming and water polo. Including swimming lessons, aqua fitness, water gymnastics, warm water exercise, aquaphobia training, family swimming etc.

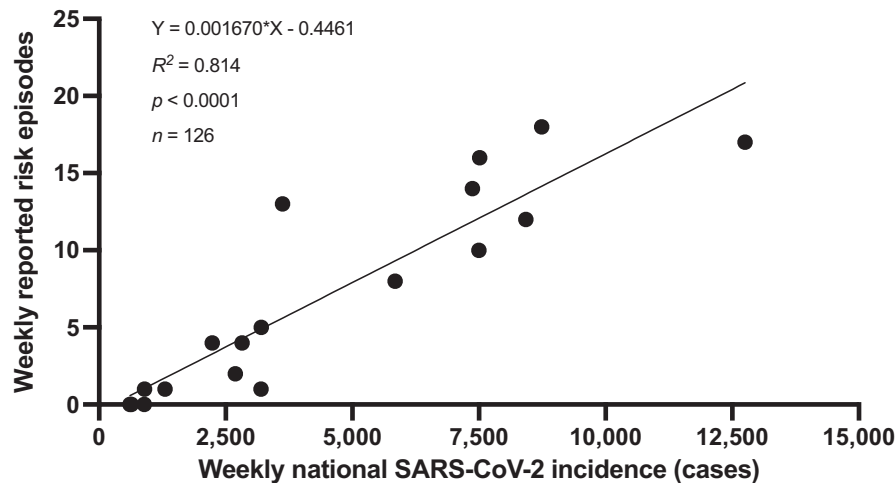


FIGURE 2 Linear correlation between weekly national SARS-CoV-2 infection incidence and number of weekly reported risk episodes. Analysis of validity of reported data. Black dots are weekly reported risk episodes for all swimming activity categories in week 32–49 ($n = 126$). Total number of weekly new SARS-CoV-2 positive cases in Denmark were diagnosed by polymerase chain reaction-based tests, which was free and easily available at the time (data from covid19.ssi.dk)

Danish region	Regional SARS-CoV-2 cases [†]	Proportion of national cases [†]	Risk episodes [‡] in the region	Proportion of national risk episodes
North Jutland	5578	0.070	7	0.056
Central Denmark	15 693	0.198	31	0.246
Southern Denmark	11 109	0.140	11	0.087
Zealand	9172	0.115	15	0.119
Danish Capital	37 870	0.477	62	0.492

TABLE 2 Regional proportions of reported risk episodes in Danish swimming clubs and nationwide Danish SARS-CoV-2 infection incidence

Note: SARS-CoV-2 infection incidence and risk episodes were only included for week 32–49 in 2020 (including both weeks).

[†]Data from covid19.ssi.dk (downloaded 19 February 2021).

[‡]Swimming activities where a SARS-CoV-2 positive subject was participating.

For 112 risk episodes, the swimming clubs reported compliance to each of 10 specific restrictions, and all participants were afterward asked to be tested for SARS-CoV-2, which enables assessment of transmission at the episode. Based on this sample, no restrictions changed the risk of transmission by statistical significance (Table 4). However, for the four restrictions that had transmission episodes in both groups, it was possible to calculate power, which proved to be low (power < 0.07). The effect of hand hygiene was not possible to estimate because all risk episodes of this analysis complied to hand hygiene.

Although numbers are small, the number of restrictions that were followed at all 112 risk episodes and at the eight transmission episodes, does not appear to differ (Figure S2).

For 106 risk episodes, 55 swimming clubs reported the group size (Figure 4). The mean group size at these risk

episodes was 14.6 (95% CI: 12.9;16.3). The restriction of group sizes to 50 participants, including coaches, was adhered to at all but one risk episode.

3.5 | Chlorine concentrations

A low response rate was seen on free chlorine concentrations in swimming pools as a result of lack of knowledge on this subject. This is likely because chlorine concentrations are not the responsibility of most swimming clubs, but instead the local municipality that administers swimming pools.

Thirty four respondents (19.8%) knew their swimming pools' free chlorine concentrations. Of these 16 clubs (43.2%) reported an increase in free chlorine concentrations at least once after the beginning of the COVID-19

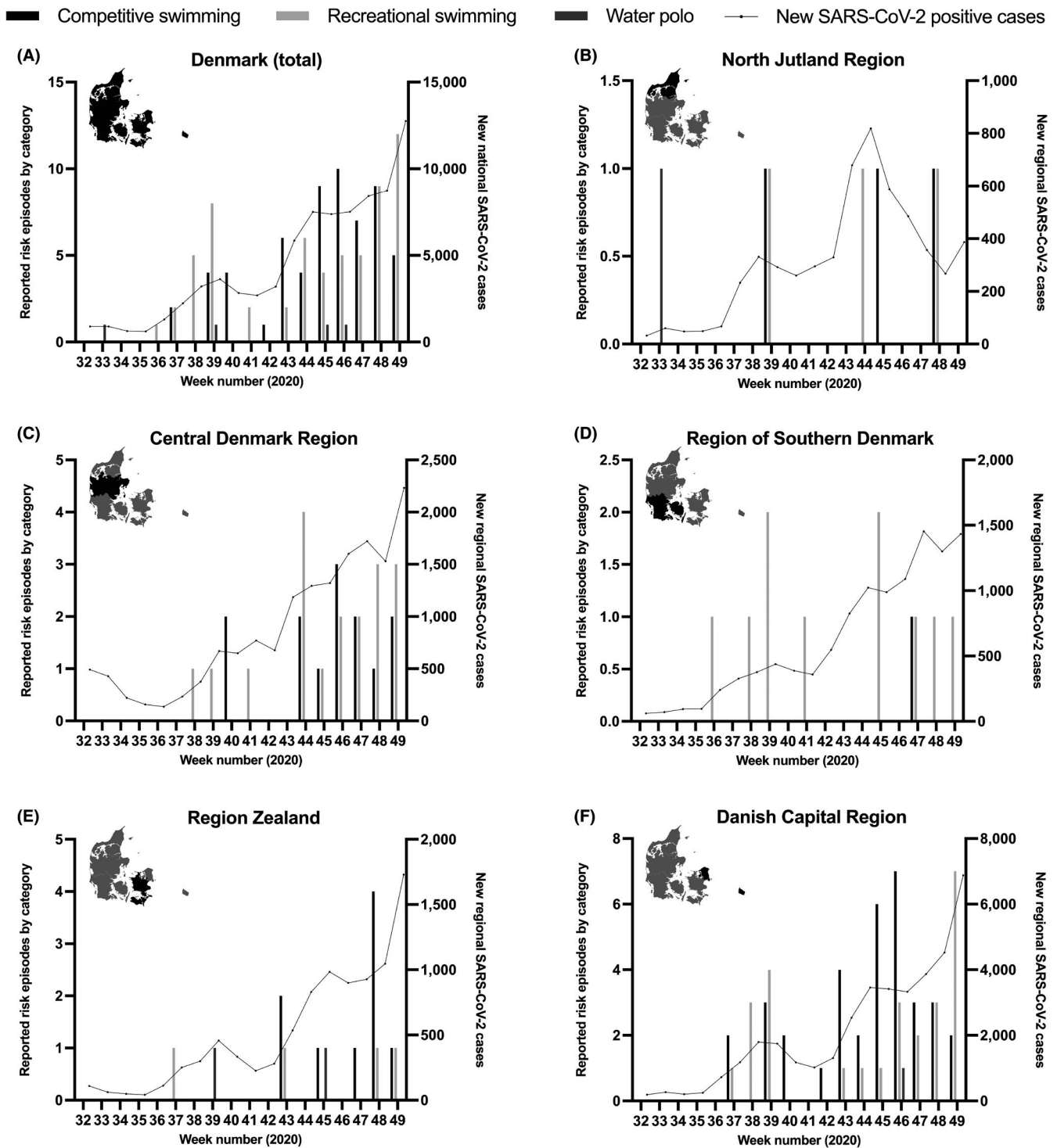


FIGURE 3 Geographic distribution of weekly reported risk episodes compared to total weekly SARS-CoV-2 infection incidence. Analysis of validity of reported data. One hundred twenty six risk episodes (swimming activities where a SARS-CoV-2 positive subject was participating) were included, as they were reported to happen in week 32–49 in 2020. Bars represents weekly risk episodes. Total number of weekly new SARS-CoV-2 positive cases from each geographic region were diagnosed by polymerase chain reaction-based tests, which was free and easily available at the time (data from covid19.ssi.dk). Connected dots represents weekly cases

pandemic. Before the COVID-19 pandemic, the average swimming pool free chlorine concentration level was reported to be between 0.5–0.8 mg/L; after the increases, the

average level was reported to be between 0.8–1.2 mg/L. No reports of lowered free chlorine concentrations were recorded.

TABLE 3 Descriptive results for each category of swimming activity in 172 swimming clubs

	Total	Competitive swimming		Recreational swimming [‡]		Water polo	
		Training	Competition	Training	Competition	Training	Competition
Risk episodes [†]	162	69	10	79	0	3	1
Transmission episodes [‡]	8	5	2	1	0	0	0
Fraction [§]	0.049	0.072	0.200	0.013	-	0.000	0.000
Participants infected [¶]	23	15	6	2	0	0	0

[†]Swimming activities where a SARS-CoV-2 positive subject was participating. Only risk episodes where all close contacts afterward were tested were included.

[‡]Risk episodes where other participants subsequently tested positive for SARS-CoV-2.

[§]Transmission episodes divided by risk episodes.

[¶]Number of infected participants other than the initially infected person.

[‡]Any swimming activities but competitive swimming and water polo. Including swimming lessons, aqua fitness, water gymnastics, warm water exercise, aquaphobia training, family swimming etc.

TABLE 4 Effect of every individual restriction

Restriction	RD [‡] (95% CI)	RR [§] (95% CI)	P Value [†]	Power	n (f/nf) [¶]
1 meter distance between sports bags	-7.9 (-24.1;8.2)	0.44 (0.11;1.83)	.36	.02	84 (63/21)
No shared equipment	9.8 (3.3;16.2)	-	.20	-	106 (82/24)
2 meters distance on land, high intensity	12.5 (4.4;20.6)	-	.34	-	79 (64/15)
Disinfection of lockers after use	7.4 (0.4;14.4)	-	.57	-	69 (54/15)
No physical activities around pool area	-10.4 (-26.7;5.9)	0.31 (0.07;1.26)	.12	.07	107 (87/20)
1 meter distance in water	6.8 (1.6;12.1)	-	>.99	-	101 (88/13)
Water bottles filled from home	-15.2 (-40.5;10.2)	0.24 (0.05;1.27)	.14	.05	72 (62/10)
Shower before and after	-4.1 (-25.2;17.0)	0.63 (0.09;4.57)	.51	.01	109 (100/9)
1 meter distance on land, low intensity	5.1 (0.7;9.5)	-	>.99	-	101 (98/3)
Hand hygiene	-	-	-	-	96 (96/0)

Note: Total number of responses to questions on individual restrictions varied depending on whether the respondent knew the answer or not. Risk refer to the probability of transmission of SARS-CoV-2 at a swimming activity, where a SARS-CoV-2 positive subject was participating. Empty cells (hyphens) are caused by a zero in one or more cells of the 2 × 2 contingency table. All respondents answering the question on hand hygiene reported good compliance, why no RD or RR were estimated for this restriction.

[‡]RD, risk difference. %-point.

[§]RR, risk ratio.

[†]Fisher's exact test. Significance level = 0.005 (Bonferroni correction: 0.05/10)

[¶]f = number of responses reporting compliance. nf = number of responses reporting non-compliance. n = total number of responses.

4 | DISCUSSION

This study reports 162 risk episodes including eight transmission episodes at which SARS-CoV-2 is likely to have been transmitted during indoor swimming activities. These numbers should be considered in the perspective, that the survey is based on the activity of 82.7% of all members of DSF member clubs (159 807 persons). In addition, the prevalence of SARS-CoV-2 in Denmark as well as the restrictive measures in effect in the study period should be kept in mind.

The percentage of risk episodes leading to transmission of SARS-CoV-2 is overall 4.9%, and although this

percentage appears to differ between competitive swimming (8.9%) and recreational swimming (1.3%), there is no statistically significant difference (Fisher's exact test: $p = 0.063$, power = 0.444). The numbers are estimates of the risk of transmission to occur at an indoor swimming event if a participant is SARS-CoV-2 positive. Owing to methodological limitations, the apparent difference between competitive swimming and recreational swimming should be interpreted with caution (see limitations below).

As the risk episodes exposed on average 13.6 (95% CI: 11.9;15.3) participants to SARS-CoV-2, in total 2201 (95% CI: 1923;2479) swimmers are estimated to have been exposed to SARS-CoV-2 at the recorded risk episodes. Of

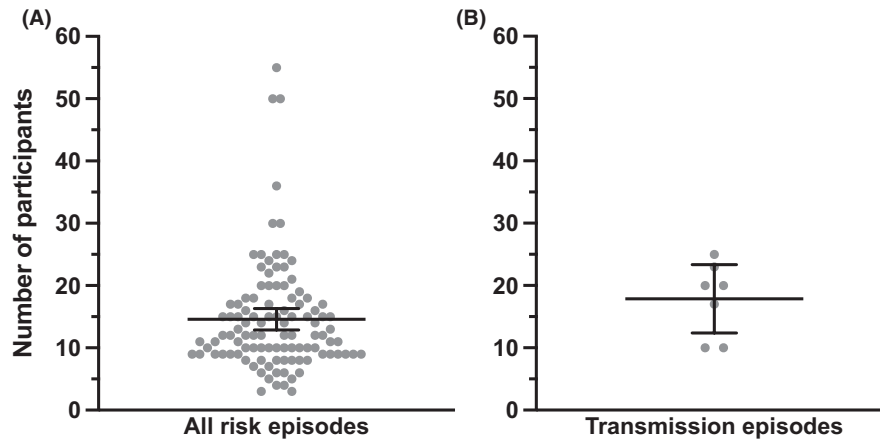


FIGURE 4 Group size at risk and transmission episodes. (A) One hundred six risk episodes (swimming activities where a SARS-CoV-2 positive subject was participating) in 55 swimming clubs. Minimum: 3. Maximum: 55 Mean: 14.58 participants. 95% confidence interval: (12.87;16.39). (B) Seven transmission episodes are risk episodes where other participants subsequently tested positive for SARS-CoV-2. These episodes are also included in Figure 4A. Minimum: 10. Maximum: 25. Mean: 17.86. 95% confidence interval: (12.37;23.34). Y-axis shows total number of participants in the groups of the SARS-CoV-2 positive subject. More people might have been in the swimming pool facilities but keeping two meters distance to other groups. Every gray dot represents one group at one risk episode. Wide horizontal bar represents mean, narrow horizontal bars represent 95% confidence limits

these swimmers, 23 subsequently tested positive for SARS-CoV-2, leading to an estimated risk of infection of 1.0 (95% CI: 0.9;1.2)% by participating in a risk episode. This number is an estimate of a participant's risk of getting infected with SARS-CoV-2 at an indoor swimming activity (under the restrictions prevailing in the study period) if another participant is SARS-CoV-2 positive. For comparison, a cohort study showed SARS-CoV-2 transmission from non-hospitalized COVID-19 patients to 12%–24% of close contacts, that is, health care-workers, household contacts, nursing home workers or residents.¹⁸ Further, an observational study of Danish households found SARS-CoV-2 transmission to 48% of household residents within 14 days after the primary case tested positive.¹⁹

Competitive swimming comprises <5% of DSF members but accounted for an estimated 39.4% of the three swimming activity categories' pool activity hours during the period under study. When normalizing to pool activity hours the incidence rate analysis also suggests there was a higher rate of transmission during competitive swimming than during recreational swimming. This suggests that SARS-CoV-2 spreads easier in a competitive swimming setting than in recreational swimming. This is in line with the observation that intense physical activity might increase susceptibility to upper respiratory infections.²⁰ However, this finding is contradictory to the results of a small cohort study, that training in competitive swimming does not change susceptibility to upper respiratory infections in general.²¹ A higher transmission rate in competitive swimming could also be explained by a higher number of swimmers per lane, making it harder to keep the required in water distance. Moreover,

competitive swimmers may engage more socially as they are more uniform in age and spend more hours together, making them prone to closer contact during swimming activities.

Yet, the apparent difference between competitive and recreational swimming might also be explained by more complete reporting from the competitive swimming activities. Although no statistically significant difference in sampling of risk episodes was found, swimming clubs in general have a better overview and more precise knowledge of competitive than recreational swimming activities, which could cause a sampling bias favoring reporting from competitive swimming. Also, it was not possible to control confounding factors like the age distribution between recreational and competitive swimming. Though, as individuals under 20 years of age are estimated to have half the susceptibility to SARS-CoV-2 infection than adults above this age,²² and most Danish competitive swimmers are below 20 years of age, susceptibility by age is not likely to explain the results.

The data suggest a high compliance to most of the 10 restrictions in the risk episodes during the pandemic. The highest compliance was to hand hygiene. This was higher than some previous research on behavior during the COVID-19 pandemic^{23–25} and on level with other.²⁶ The risk assessment analysis failed to demonstrate a correlation between individual restrictions followed or the number of restrictions followed and the risk of transmission of SARS-CoV-2. Low statistical power suggests that this may have been a result of a low number of transmission episodes and a small sample in general. As we sampled the risk episodes in a comprehensive proportion of swimming

clubs, a much larger sample might be difficult to achieve. In addition to lack of power, one should keep the risk of social desirability bias in self-reported data in mind when interpreting these results, as they may not mirror the true compliance (see limitations below).

A few reported risk episodes associated with activities in Danish swimming clubs were not included in the analysis because they were actually other activities than indoor swimming sessions, for example, boxing training and sauna after outdoor swimming. Of special notice is a training camp lasting 8 days, at which 23 swimmers from the same club were infected with SARS-CoV-2. Other clubs training in the same swimming pool in the same period did not report infected participants, and the exact time and source of transmission were never identified. Although transmission may have occurred during swimming activities at the training camp, this cannot be isolated from transmission associated with other activities during the training camp, such as sleeping in dormitories, dining and socializing.

4.1 | Limitations

This study had several limitations. First, the retrospective design makes the study prone to recall bias. Second, some clubs reported to the survey based on logbooks of activities with notes of all risk episodes and results of follow-up tests, whereas other clubs may have collected the information while answering the questionnaire. Third, the questionnaire's reliability was not measured using repeated questions.

Some degree of recall bias may also be assigned to respondents' hope for a certain outcome: Some respondents wrote as a final comment, that they looked forward to seeing the study results, as they were hoping for restrictions to be removed. This might have interfered with their recalling of compliance to individual restrictions at risk episodes. As noted above, the precise knowledge also may have varied depending on the respondents' role in the club, which adds variability to the general recall bias. Only a minor fraction of respondents were coaches or instructors being present at the swimming pool during training and competition. Therefore, some respondents may have reported intended rather than actual compliance to some restrictions.

In theory, the type and size of the swimming facility could influence the risk of transmission. However, as the 1 m distance in water was reported to have been enforced at 86% of swimming activities (Figure S1), this has likely only made a minor contribution to the risk of transmission. In future studies, the type and size of facilities should be recorded.

As activity measure, we choose "pool activity hours", as this number is readily available in most clubs. For risk episodes, we also recorded number of participants. But it would have been optimal to have also recorded number of participants in all other activities to have a more detailed measure of the amount of activity. However, during the design phase we concluded, that if we should ask for this information, many clubs would not have volunteered to participate in the study, and we accepted this limitation to ensure a large response rate.

It was not possible to isolate the circumstances of risk episodes to activities in the pool water exclusively. Risk episodes possibly involved contact between participants in the changing room, during shower, and during transportation to and from the swimming pool premises. These activities may also differ between swimming activity categories. Also, as competitive swimmers generally are young people, they might attend the same school, for example, dedicated classes for sport talents.

It is still debated how large a proportion of infected individuals are asymptomatic but able to transmit the virus to others.²⁷ A study showed 7.9% (6.6%–8.8%) of Danish blood donors to be seropositive in week 6 in 2021 (8–14 February).²⁸ At the same time, only 3.5% of the Danish population had been tested positive for SARS-CoV-2 at least once.² The discrepancy may indicate a large number of people not being tested, even though tests during most of the pandemic were free and easily available in Denmark. As the identification of risk episodes in this study depended on the detection of infected participants through voluntary screening by publicly available PCR tests, the presence of infected but non-tested (likely asymptomatic) participants in swimming activities would not have been recorded. Consequently, the real number of risk episodes may therefore have been higher than the reported number. However, the good fit of data to the regional and national distribution of SARS-CoV-2 positive cases supports the assumption that the recorded risk episodes were a representative sample of the population of risk episodes. This also supports the data collection as valid to estimate the primary outcome.

To unify reporting and prevent recall bias of risk episodes, we defined a risk episode as "one infected person participating in swimming activities," no matter how many swimming activities the person participated in. Accordingly, some infected subjects may have participated in more than one swimming activity before they were tested SARS-CoV-2 positive. The reporting of number of participants in risk episodes should partly compensate for the resulting underestimation of risk episodes, as this reporting enabled the respondent to report the total number of participants exposed to the presence of the SARS-CoV-2 positive participant defining the risk episode.

The reporting of transmission episodes was limited by the ability of the swimming clubs to ensure testing of all participants at a risk episode. According to widely communicated national guidelines, subjects in close contact with SARS-CoV-2 infected subjects should be tested. At all 162 risk episodes used to estimate transmission fractions and incidence rates, all participants were informed about these guidelines and asked to follow them. For the analyses, it was assumed that this instruction was followed, but the degree of compliance to the instruction cannot be quantitated in this study.

No confounding factors were identified. As transmission was a rare event, the statistical analyses would have needed a larger sample to have enough power. However, as stated, the study included 82.7% of all members in DSF member clubs, so the potential for increasing sample size is limited.

5 | CONCLUSIONS

Based on replies from 172 Danish swimming clubs eight out of 162 risk episodes (4.9%) lead to infection of 23 participants, which constituted an estimated 1.0 (95% CI: 0.9;1.2)% of all participants in risk episodes. This corresponds to transmission of SARS-CoV-2 to 19.5 participants per 100 000 pool activity hours.

Compliance to 10 restrictions at risk episodes was between 69.9% and 98.1% with hand hygiene having highest compliance. No individual restrictions were found to change the risk of transmission, but this analysis had low statistical power.

6 | PERSPECTIVES

Controlled exposure experiments are very difficult to conduct using the SARS-CoV-2, but because of the unmatched surveillance of infections, the COVID-19 pandemic is a unique setting to investigate respiratory infections across different sports. As the most commonly reported infectious diseases in sports are viral and bacterial skin infections, this is a great chance of extending our knowledge.²⁹

The generalizability of the results is limited by the special circumstances during the restricted opening of Danish swimming activities in the second half of 2020. Nonetheless, the results provide a unique overview of risk episodes and transmission episodes in a large cohort taking part in swimming activities during the COVID-19 pandemic. These data are valuable as a foundation to design and implement restrictions on sports activities, seeking an optimal balance between costs and benefits in future pandemic or local epidemic scenarios.

ACKNOWLEDGEMENTS

The Danish Swimming Federation is thanked for collaborating in this study by distributing the questionnaire to its member clubs, sending out reminders and performing follow-up phone calls. The authors further would like to thank development consultant Lars Bo Larsen of the Danish Swimming Federation for sharing his expertise and knowledge on organized swimming activities in Denmark.

The authors received no financial support for the research, authorship or publication of this article.

CONFLICTS OF INTEREST

MBT and AVC declare that they have no conflicts of interest. SF serves voluntarily as official in a swimming club under the Danish Swimming Federation and has a close relative practicing competitive swimming.

AUTHOR CONTRIBUTIONS


MBT, AVC and SF conceived and designed the study. MBT collected data in collaboration with Danish Swimming Federation. MBT and SF analyzed the data. MBT prepared tables and figures. MBT, AVC, and SF interpreted the data and wrote the manuscript, with MBT writing the first draft and AVC and SF revising during several rounds. MBT, AVC, and SF all approved the final version and are responsible for the study according to the policy for research integrity, freedom of research and responsible conduct of research at Aarhus University.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, SF. The data are not publicly available because of information that could compromise research participants' privacy (swimming clubs).

ORCID

Martin Brink Termansen  <https://orcid.org/0000-0003-2690-3403>

Ask Vest Christiansen  <https://orcid.org/0000-0001-6115-6314>

Sebastian Frische  <https://orcid.org/0000-0002-0270-3602>

REFERENCES

1. World Health Organization. WHO Director-General's opening remarks at the media briefing on COVID-19 - 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> Accessed December 21, 2020.
2. Statens Serum Institut. COVID-19 Overvågningsdata 14092021. <https://covid19.ssi.dk/overvagningsdata/download-fil-med-overvaagningdata> Accessed September 15, 2021.

3. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med.* 2020;382:727-733.
4. World Health Organization. Technical guidance: naming the coronavirus disease (COVID-19) and the virus that causes it. [https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-\(covid-2019\)-and-the-virus-that-causes-it](https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it) Accessed February 11, 2020.
5. World Health Organization. Transmission of SARS-CoV-2: implications for infection prevention precautions. <https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions> Accessed December 21, 2020.
6. Hansen TS, Stephensen EK. Danmark lukker ned: Her er regeringens nye tiltag. <https://nyheder.tv2.dk/samfund/2020-03-11-danmark-lukker-ned-her-er-regeringens-nye-tiltag> Accessed December 21, 2020.
7. Ministry of Culture. Nu genåbner endnu mere idræt og foreningsliv. <https://www.anpdm.com/newsletterweb/46455E4A7047415B4672404459/42475C4173434B5F467144465C4671> Accessed March 2, 2021.
8. Danish Swimming Federation, National Olympic Committee and Sports Confederation of Denmark, Danish Gymnastics and Sports Associations. Vand sportens Coronaregler. https://www.svoem.org/_files/corona/udspecificeringafretningslinjerfor-egnbningsafsvmmeklubber_21.september2020.pdf Accessed January 3, 2021.
9. The Danish Environmental Protection Agency. Mere klor i svømmehaller med særligt lavt klorindhold skal beskytte mod corona. <https://mst.dk/service/nyheder/nyhedsarkiv/2020/jul/mere-klor-i-svoemehaller-med-saerligt-lavt-klorindhold/> Accessed December 21, 2020.
10. Li Y, Leung GM, Tang JW, et al. Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review. *Indoor Air.* 2007;17:2-18.
11. Barna Z, Kádár M. The risk of contracting infectious diseases in public swimming pools. A review. *Annali Dell'istituto Superiore Di Sanità.* 2012;48:374-386.
12. Yeo C, Kaushal S, Yeo D. Enteric involvement of coronaviruses: is faecal-oral transmission of SARS-CoV-2 possible? *Lancet Gastroenterol Hepatol.* 2020;5:335-337.
13. Bonadonna L, La Rosa G. A review and update on waterborne viral diseases associated with swimming pools. *Int J Environ Res Public Health.* 2019;16(2):166.
14. La Rosa G, Bonadonna L, Lucentini L, Kenmoe S, Suffredini E. Coronavirus in water environments: occurrence, persistence and concentration methods - A scoping review. *Water Res.* 2020;179:115899.
15. Goh GK, Dunker AK, Foster JA, Uversky VN. Shell disorder analysis predicts greater resilience of the SARS-CoV-2 (COVID-19) outside the body and in body fluids. *Microb Pathog.* 2020;144:104177.
16. Brown JC, Moshe M, Blackwell A. Inactivation of SARS-CoV-2 in chlorinated swimming pool water. *bioRxiv.* 2021. <https://doi.org/10.1016/j.watres.2021.117718>
17. The Prime Ministers Office. Pressemøde den 7. December 2020. <https://www.stm.dk/presse/pressemoedearkiv/pressemoede-den-7-december-2020/> Accessed March 9, 2021.
18. Marks M, Millat-Martinez P, Ouchi D, et al. Transmission of COVID-19 in 282 clusters in Catalonia, Spain: a cohort study. *Lancet Infect Dis.* 2021;21:629-636.
19. Lyngse FP, Mølbak K, Træholt Frank K, Nielsen C, Skov RL, Kirkeby CT. Association between SARS-CoV-2 transmission risk, viral load, and age: a nationwide study in Danish households. *medRxiv.* 2021;2021.02.28.21252608.
20. Shephard RJ. Overview of the epidemiology of exercise immunology. *Immunol Cell Biol.* 2000;78:485-495.
21. Gleeson M, McDonald WA, Pyne DB, et al. Immune status and respiratory illness for elite swimmers during a 12-week training cycle. *Int J Sports Med.* 2000;21:302-307.
22. Davies NG, Klepac P, Liu Y, Prem K, Jit M, Eggo RM. Age-dependent effects in the transmission and control of COVID-19 epidemics. *Nat Med.* 2020;26:1205-1211.
23. Kebede Y, Yitayih Y, Birhanu Z, Mekonen S, Ambelu A. Knowledge, perceptions and preventive practices towards COVID-19 early in the outbreak among Jimma university medical center visitors, Southwest Ethiopia. *PLoS One.* 2020;15:e0233744.
24. Lau LL, Hung N, Go DJ, et al. Knowledge, attitudes and practices of COVID-19 among income-poor households in the Philippines: a cross-sectional study. *J Glob Health.* 2020;10:011007.
25. Almutairi KM, Al Helih EM, Moussa M, et al. Awareness, attitudes, and practices related to coronavirus pandemic among public in Saudi Arabia. *Fam Community Health.* 2015;38:332-340.
26. Prasad Singh J, Sewda A, Shiv DG. Assessing the knowledge, attitude and practices of students regarding the COVID-19 pandemic. *J Health Manag.* 2020;22:281-290.
27. Gao Z, Xu Y, Sun C, et al. A systematic review of asymptomatic infections with COVID-19. *J Microbiol Immunol Infect.* 2021;54:12-16.
28. Bloddonerne i Danmark. Bloddonor testes for overstået infektion med coronavirus. <https://bloddonor.dk/coronavirus/> Accessed April 3, 2021.
29. Turbeville SD, Cowan LD, Greenfield RA. Infectious disease outbreaks in competitive sports: a review of the literature. *Am J Sports Med.* 2006;34:1860-1865.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Terman MB, Christiansen AV, Frische S. SARS-CoV-2 prevalence and transmission in swimming activities: Results from a retrospective cohort study. *Scand J Med Sci Sports.* 2022;32:242-254. <https://doi.org/10.1111/sms.14071>