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# Risk of SARS-CoV-2 transmission from on-field player contacts in amateur, youth and professional football (soccer)

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## ABSTRACT

**Objective** To investigate the risk of transmission among potentially infectious SARS-CoV-2-positive football players while participating in training or matches at amateur, youth and professional levels.

**Methods** Between August 2020 and March 2021, football players who tested positive for SARS-CoV-2 and participated in matches or training during the period of potential contagiousness were identified through media search (professional level) and a nationwide registry in Germany (amateur and youth level) to determine symptoms, source of infection and hygiene measures adopted. The definition of potentially infectious players was based on the time of a positive PCR testing and symptom onset. Transmission-relevant contacts on the pitch were evaluated through doubly reviewed video analysis.

**Results** Out of 1247 identified football matches and training sessions (1071 amateur and youth level, 176 professional level), 104 cases (38 training sessions, 66 matches) with 165 potentially infectious players were detected. Follow-up PCR testing at the professional level (44 cases) revealed no transmission. At the amateur and youth level, the combination of partial PCR testing (31 of 60 cases) and symptom monitoring within 14 days post-exposure (46 of 60 cases) identified 2 of 60 matches in which follow-up infections occurred that were attributed to non-football activities. This is consistent with the video analysis of 21 matches demonstrating frontal contacts were <1 per player-hour (88%, 30 of 34 players), each lasting no longer than 3 s.

**Conclusion** On-field transmission risk of SARS-CoV-2 in football is very low. Sources of infections in football players are most likely not related to activities on the pitch.

## INTRODUCTION

During the COVID-19 pandemic, various hygiene measures have been implemented in football and other team sports to reduce the transmission of SARS-CoV-2. The effectiveness of these measures has certain limitations, of which non-compliance is a significant one. Once an athlete has been infected, the question arises as to whether this has happened in connection with the team sport being played or in a different environment. For a better distinction between these two sources, analysis of transmission-relevant contacts can be used as a reasonable approach to assess the risk of infection of the respective sport.

In football, a few studies exist on the specific contact patterns and potential risk of respiratory disease transmission on the pitch.<sup>1–3</sup> The average exposure time per pair of individuals in a professional football match was 32 s, assessed by means of a tracking system.<sup>1</sup> In a video-based analysis of three matches with 18 potentially infectious SARS-CoV-2-positive football players, contact with the mucosa of the mouth, nose and eyes (potential source of virus transmission) in infected players was less frequent than reported in everyday situations.<sup>2,4</sup> A more extensive video-based analysis of 50 football matches showed that typical player actions associated with increased aerosol and droplet production (speaking, shouting, spitting) were very rare.<sup>3</sup> In rugby, despite tackle involvements and close interactions, no SARS-CoV-2 transmission was detected in 128 players exposed to 8 infected players during four matches.<sup>5</sup>

Considering the small number of infected players in previous studies,<sup>2,5</sup> the aim of this study was to investigate the risk of transmission in a larger number of potentially infectious SARS-CoV-2-positive football players inadvertently participating in training or matches based on a nationwide reporting system, a media search and a video analysis.

## METHODS

This study was conducted between August 2020 and March 2021.

## General design

Identification of SARS-CoV-2-positive players from different playing levels was realised as follows:

1. Professional level: professional players (German first to third divisions, European first divisions, national teams) officially confirmed as SARS-CoV-2-positive by their clubs or associations were prospectively identified through daily media searches via common search engines ([www.google.com](http://www.google.com)) and football-specific platforms ([www.goal.com](http://www.goal.com), [www.spx.com](http://www.spx.com)). Media reports were reviewed for onset and manifestation of COVID-19-related symptoms, timing of PCR and hygiene measures applied. Where feasible, team physicians of the clubs (consent of players provided) were additionally interviewed.
2. Amateur and youth level: a nationwide registry has been set up for all SARS-CoV-2-positive amateur players in Germany (fourth division or lower) and youth players. Players were recruited with the support of 20 cooperating



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regional chapters of the German Football Federation (DFB, Deutscher Fußball-Bund) by providing lists of match and training cancellations due to SARS-CoV-2-infected players (mandatory reporting system for clubs). Then, contact was established with the affected clubs, who were asked to pass on a standardised questionnaire (online supplemental material S1) to the infected players (parents in case of minors). Items included clinical data of the infected players, testing procedures and hygiene measures applied by the local health authorities. Similarly, representatives of the opponents were contacted and interviewed regarding the presence of COVID-19-related symptoms for the period of 14 days post-match. All players provided written informed consent prior to participation. In addition, all regional chapters sent out the standardised questionnaire to their affiliated clubs at intervals of 1–2 months, which served as a reminder. Most of the data collection in amateur football ended when the German fifth division and lower divisions were suspended due to COVID-19 restrictions at the end of October 2020 and continued only for the fourth division (suspended during November 2020) until the end of March 2021. Participating players were not involved in the planning of our research.

### Testing procedure

According to the requirements of the professional football leagues, national and international football association professional players underwent SARS-CoV-2 dual-target (at least two independent gene regions) PCR testing a maximum of 48 hours before the match and were part of a regular testing procedure at least twice a week.

Amateur and youth players in Germany were not part of a regularly scheduled testing process and PCR testing took place on a voluntary basis in public healthcare institutions. In both professional and amateur players, nasopharyngeal and/or oropharyngeal swabs were taken by trained healthcare professionals and PCR performed by accredited laboratories. During the study period, genome sequencing of SARS-CoV-2 was mandatory for all laboratories in Germany and was performed for 5% of all positive samples, according to the German Robert Koch Institute.

### Eligibility criteria

Football players testing positive for SARS-CoV-2 by PCR were included in the study if there was a substantial likelihood of infection (with or without COVID-19-related symptoms) during participation in training or match play.

#### Professional players

Both of the following had to apply:

1. SARS-CoV-2 PCR was negative 48 hours before match or training.
2. Within 48 hours after match or training SARS-CoV-2 PCR was positive (asymptomatic infection) or COVID-19-related symptoms (online supplemental material S2) occurred confirmed by a subsequent SARS-CoV-2-positive PCR.

#### Amateur and youth players

One of the following had to apply:

3. Typical COVID-19-related symptoms occurring within 48 hours after match or training confirmed by a subsequent SARS-CoV-2-positive PCR.
4. Voluntary PCR within 48 hours after match or training was SARS-CoV-2-positive (asymptomatic infection) and history was positive for high-risk contact (infected person,

transmission event) up to 5 days (mean incubation period)<sup>6,7</sup> before match or training, indicating acute infection.

For symptomatic players (criteria 2 and 3), a 48-hour window after match or training was chosen to be within the range of peak contagiousness for SARS-CoV-2, which is approximately within 2 days before the onset of symptoms.<sup>8</sup> Similarly, for asymptomatic players (criteria 4), peak contagiousness was estimated 2 days after a 5-day incubation period as calculated previously.<sup>9</sup>

### Video analysis

For professional clubs, the video footage was provided by the German Football League (DFL, Deutsche Fußball Liga), the DFB and the UEFA. At the amateur and youth level, publicly accessible streaming portals ([www.sporttotal.tv](http://www.sporttotal.tv), [www.youtube.com](http://www.youtube.com)) were used or the video footage was made available directly by the clubs. All video recordings were available in uncut version for the full match length and were filmed from the same perspective (ie, standard view from the midline). Video analysis was performed by two independent reviewers, who evaluated the quality of contacts of each infected player during the matches. The focus was on within-player contacts (face or head touches) and between-player contacts (duels, hand-slaps, conversations, group formations) including all potential transmission routes of SARS-CoV-2 (close contacts, droplet infection and aerosols).<sup>10–12</sup> In this context, it was considered that aerosol transmission is recognised as the main route of transmission,<sup>13 14</sup> although the risk of aerosol transmission is lower outdoors.<sup>15–17</sup>

Duels were further categorised into frontal and lateral contacts or into those during which players were positioned behind each other. Additionally, all hand-to-ball contacts during matches, such as throw-ins, kick-outs, throw-outs and attempts to place the ball before corner-kicks, free-kicks, goal kicks and kick-offs, were counted. Furthermore, contact to the face with or without contact to the mucosal membrane (mouth, nose and eyes) and headers were assessed for each infected player. All videos were analysed in real time and stopped or rewound as often as needed. Each reviewer conducted at least two full-time sessions per video match to ensure that all relevant contacts of each infected player were captured. When the number of observed contacts differed, the higher number was taken.

### Statistics

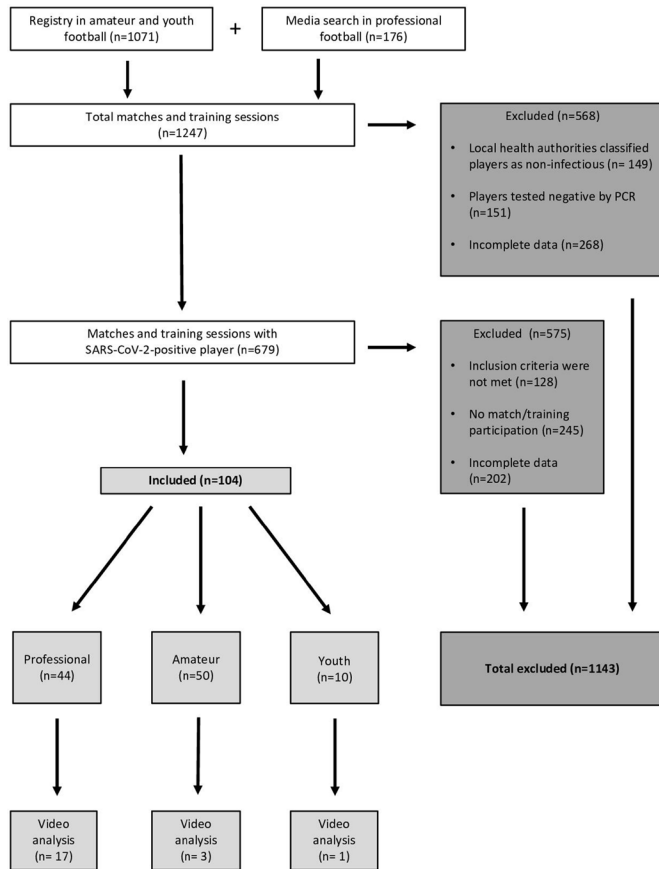
The analysis is mainly descriptive. Data are given as mean±SD or median with IQR.

### RESULTS

A total of 104 cases (38 training sessions, 66 matches) with 165 potentially infectious players (85 professional and 59 amateur players (age 25.7±3.0 years) and 21 youth players (15.6±0.8 years)) from 14 countries were included in the study. A detailed flow diagram of case recruitment ([figure 1](#)) and an overview of the playing levels including 13 UEFA competitions ([table 1](#)) are presented separately. In 44 cases at the professional level, clubs publicly announced their players as SARS-CoV-2-positive (including potential symptom onset) within 48 hours (75%), on day 3 (18%) or on day 4 (7%) after match or training. Additionally, team physicians of professional clubs were interviewed in 11 of 44 cases (25%), all of whom confirmed the accuracy of media information.

### Transmission during training sessions and matches

At the professional level, all 44 cases (6 training sessions, 38 matches) with potentially infectious players resulted in no virus



**Figure 1** Flow diagram. Football matches and training sessions with confirmed and suspected SARS-CoV-2-positive players on the pitch.

transmission on the pitch as verified by repeated dual-target PCR testing ( $\geq 2 \times$  per week) within 14 days after the particular activity. At the amateur level and in youth football, voluntary PCR testing was performed in all initially infected (index) players at least once and in the exposed players in 31 of 60 cases (14 training sessions and 17 matches). In 29 of these 31 cases (94%), all exposed players remained SARS-CoV-2-negative after

$5.7 \pm 3.1$  days. In only two cases could the virus transmission on the pitch not be clearly ruled out. In one case nine players (including seven players from the opposing team) tested positive for SARS-CoV-2 within 3–5 days after exposure to an infected player, who showed COVID-19-related symptoms on the first day post-match. Both teams involved reported a transmission event, both in the private environment (two players) and as part of a COVID-19 outbreak in the club (seven players). In the second case 11 players (including 1 player from the opposing team) tested positive for SARS-CoV-2 within 4–7 days after exposure to an infected player. In one team, a shared bus ride with the infected player, during which no face masks were worn, has been reported as the potential source of infection (10 players and several staff members tested positive). The player of the opposing team reported a transmission event in his occupational environment.

### COVID-19-related symptoms

COVID-19-related symptoms ( $\geq 2$  per player) were reported in 62 of the 165 (38%) index players with a mild to moderate course (online supplemental material S2). At the amateur level, symptom monitoring within 14 days after exposure to a potentially infectious player during 60 training sessions or matches (response rate 77%, 46 of 60 cases) revealed that 11 exposed players showed COVID-19-related symptoms (online supplemental material S3). Five of these players tested positive (highly suspected infection source: private meeting with teammates within 5–6 days prematch) and two players tested negative for SARS-CoV-2 by PCR within 7 days post-exposure. Four of the 11 exposed players were from opposing teams and tested SARS-CoV-2-positive by PCR between 3 and 7 days post-exposure. All four players clearly attributed their infection to a transmission event before the match in their occupational and private environment.

### Hygiene measures

In 82 of 104 training sessions or matches, hygiene measures established by the local health authorities were reported. Of these 82 cases, quarantine for the infected player alone was applied in 52 cases (63%) and quarantine for the entire team in

**Table 1** Competitions and playing levels of 104 teams with potentially infectious SARS-CoV-2-positive players including 21 video analyses during match

Professional level	n	Amateur level	n	Youth	n	Video analysis	n
German Bundesliga	9	German fourth division	5	Academy	2	German Bundesliga	2
German second division	4	German fifth division	2	No academy	8	German second division	1
German third division	5	German sixth division	2			German third division	3
UEFA Nations League	8	German seventh division	10			UEFA Nations League	9
La Liga	3	German eighth division	12			UEFA Champions League	2
Test match of national teams	3	German ninth division	11			UEFA Europa League	1
Serie A	2	German 10th division	6			German fourth division	2
UEFA Champions League	2	German 11th division	1			Youth (academy)	1
UEFA Europa League	2	German veterans league	1				
FIFA World Cup qualification	1						
UEFA Under-21 European Championship qualification	1						
Africa Cup of Nations qualification	1						
Premier League	1						
Eredivisie	1						
Premjer Liha	1						
Total	44		50		10	Total	21

29 cases (35%). In one case (1%), a wait-and-watch strategy was adopted. The proportion of individual versus team quarantine was 58%, 65% and 26%, and 42%, 35% and 74% in amateur, professional and youth players, respectively. In 13 of 104 cases, index players reported careless contact behaviour prior to match or training (private party  $n=6$ , team meetings without masks  $n=4$ , communal meals  $n=3$ ). In three cases, prematch test results were not awaited and subsequently turned out to be SARS-CoV-2-positive.

### Video analysis

A total of 21 matches (professional  $n=17$ , amateur  $n=3$ , youth  $n=1$ ) with 34 potentially infectious players (goalkeeper  $n=2$ , defender  $n=10$ , midfielder  $n=12$ , striker  $n=10$ ) were analysed for transmission-relevant contacts. An overview of the individual within-player and between-player contacts per player-hour is presented in [table 2](#).

In one professional match, four of the observed players were positive for the SARS-CoV-2 variant B.1.1.7. Contacts per player-hour were in the range of the other 20 matches. An overview of the total contacts during the effective playing time of all four players and subsequent repetitive PCR testing of both teams is illustrated in [figure 2](#). The average playing time was  $71.1 \pm 25.8$  min. In each match, the maximum number of frontal duels, that is, face-to-face contacts (collisions, gathering in anticipation of a corner-kick or free-kick), was in the vast majority (88%, 30 of 34 players)  $<1$  per player-hour and lasted in no case longer than 3 s. Face-to-face conversations between players or referee were  $\leq 4$  per player-hour for all players in each match and lasted no longer than 6 s. Within-player face touches with contact to the mucous membrane (mouth, nose and eyes) were  $<10$  per player-hour in 32 of 34 players (94%). Group formation during the match (goal celebrations, set-play situations) lasted a maximum of 16 s. Hand-to-ball contacts in outfield players were  $\leq 8$  per player-hour.

### DISCUSSION

To the best of our knowledge, this is the first study to comprehensively investigate the on-field transmission risk among potentially infectious SARS-CoV-2-positive players during match and training in youth, amateur and professional football. As a main finding, a low risk of SARS-CoV-2 transmission during football match or training was observed based on PCR testing, which was performed in all cases at the professional level at least twice a week and in more than half of the cases at amateur and youth football at least once post-exposure. Additionally, symptom monitoring of amateur and youth players within 14 days post-exposure revealed no obvious evidence of viral transmission.

### On-field transmission risk of SARS-CoV-2

In the present study, analysing 104 training sessions and matches with 165 potentially infectious players, we found only two matches in amateur football in which virus transmission to the opposing team could not be completely ruled out. It must be kept in mind that alternative potential transmission routes seemed to be more likely than transmission on the pitch. In one case, seven opponents were part of a COVID-19 outbreak in the club, and in the second case one player of the opposing team reported a spreading event in his occupational environment. Similar results have been observed in rugby, where all SARS-CoV-2-positive tests post-match were associated with internal club COVID-19 outbreaks, social interactions and community transmission, rather than on-field transmission.<sup>5</sup> Furthermore,

in football, positive post-match PCR test results in players were deemed to be due to negligent behaviour prior to the match as opposed to contacts during match.<sup>2</sup> In a study monitoring the prevalence of new SARS-CoV-2 infections in more than 15 000 youth players during small-group physically distanced training, only 2 players tested positive, both infected during non-football activities.<sup>18</sup>

### Symptom monitoring

In the context of infection control, symptom monitoring is recommended to identify potential new infections.<sup>19 20</sup> In amateur and youth football, this strategy was of great importance to assess the risk of transmission of exposed players, since PCR testing alone was not a routine measure at the time of our study (only in half of all cases). We observed symptom monitoring to be uneventful in the vast majority of cases. All exposed players with COVID-19-related symptoms and subsequent SARS-CoV-2-positive PCR reported relevant off-field exposure (shared bus ride, private or occupational environment) prior to match or training.

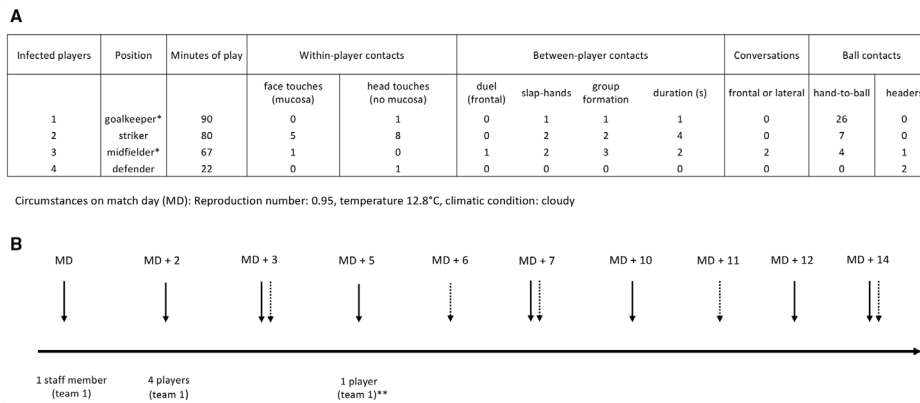
### Video analysis

In contrast to previous video analyses in football and rugby, which included three to four matches with 8–18 SARS-CoV-2-positive players,<sup>2 5</sup> our doubly reviewed video analysis followed a more comprehensive approach consisting of 21 matches including 34 potentially infectious SARS-CoV-2-positive players. Although aerosol transmission is suggested to be the primary route of SARS-CoV-2 infection,<sup>13 14</sup> the risk of aerosol transmission is lower outdoors,<sup>15–17</sup> in well-ventilated indoor areas (by increasing the air changes per hour),<sup>15</sup> and where mask-wearing (dilution of aerosol concentration  $<1\%$  at a distance  $>1$  m) and social distancing are observed.<sup>21 22</sup> In addition, there are preliminary indications (original data pending) that seating areas in a football stadium pose a smaller infection risk than crowded areas such as toilets, corridors or food and drink stands.<sup>23</sup> Nevertheless, our video analysis focused on all potential transmission routes, in addition to aerosols, droplet infection and close contacts.<sup>10–12</sup> The main focus of our video analysis was on frontal (face-to-face) and other transmission-relevant contacts. Frontal duels ( $<1$  per player-hour) and frontal conversations ( $\leq 4$  per player-hour) were rare and of short duration (duels  $<3$  s, conversations  $<6$  s). This underlines the very low risk of SARS-CoV-2 transmission, which is a direct function of contact duration.<sup>24</sup> Previous studies performing video analyses in football came to similar conclusions.<sup>2 3</sup> Notably, for the first time, our video analysis included a match with players who tested positive for the SARS-CoV-2 variant B.1.1.7, which is more transmissible than pre-existing variants.<sup>25</sup> The frequency of within-player face touches to the mucous membrane was similar to everyday situations.<sup>4 26 27</sup> Group formation during the match was no longer than 16 s, which is in line with previously observed duration of crowding during football match breaks.<sup>3</sup> Hand-to-ball contacts in outfield players occurred infrequently. However, the ball as a potential vector of virus transmission seems unlikely, as surface transmission of SARS-CoV-2 is generally considered to be low.<sup>12 28</sup> Taken together, risk contacts on the pitch between opponents are very rare and last for seconds. Thus, the contact time is by far lower than suggested in public health guidelines.<sup>20</sup> This is consistent with the low transmission rate during matches and questions the value of a quarantine for opponents.

Table 2 Transmission-relevant contacts per player-hour and median with IQR

Match	Infected players n=34	Within-player contacts			Between-player contacts					Between-player conversations			Ball contacts	
		Face touches (mucosal contact)	Head touches (non-mucosal contact)	Duel (shoulder-shoulder)	Duel (arm-arm)	Duel (front-back)	Duel (frontal)	Duel (hand-jersey)	Slap-hands	Group formation	Frontal	Lateral	Hand-to-ball	Headers
1	1	21.7	38.9	4.9	6.5	6.5	1.6	13.0	4.9	1.6	0.0	1.6	6.5	6.5
2	1	9	8	4	11	7	0	12	0	3	2	7	7	2
3	1	9.7	8.0	6.7	9.3	2.7	1.3	8.0	1.3	2.7	5.3	0	0	2.7
4	1	6.7	4.0	4.0	9.6	3.3	0	6.0	0	2.0	0.7	1.3	0	7.3
5	1	5.1	1.7	2.6	4.3	1.7	0.9	8.6	0.9	2.6	0	0	0	2.6
6	1	0.7	0	0.7	4.7	1.3	0.7	8.0	1.3	0.7	0	0	0	4.7
7	4	1.0	3.1	1.0	10.3	4.1	1.0	10.2	0	0	1.0	2.0	4.1	3.1
		8.0	3.3	2.0	3.3	6.0	0	5.3	0.7	2.0	0.7	0	1.3	4.0
		1.3	2.7	1.3	2.0	2.0	0	5.3	0.7	0	1.3	0.7	2.0	1.3
		2	0.7	3.3	5.3	1.3	0	9.3	1.3	0.7	2.0	5.3	2.7	2.7
8	4	5.3	2.0	0.7	8.7	0	0	8.0	0	0	0	2.7	0.7	0.7
		9.7	2.0	1.3	8.0	0	0	4.7	0	0.7	0	1.3	3.3	3.3
		0	0	5.7	8.6	2.9	0	28.6	2.9	0	0	0	0	0
		0	0	4	20	0	0	12	8	4	0	0	0	0
9	2	3.3	2.0	1.3	6.0	2.0	0	10.0	0	2.0	0	0	0	6.0
		9.0	2.5	5.0	12.5	7.5	0	7.5	2.5	2.5	0	0	0	2.5
10	1	1.3	0.7	2.7	7.3	1.3	0	6.0	0.7	0.7	0	0.7	0.7	2.7
11	1	4.0	1.3	2.7	6.0	0.7	0	4.0	0	1.3	0	0.7	0.7	3.3
12	1	8.0	7.3	2.0	7.3	6.7	0.7	4.0	0	6.7	0	0.7	0.7	4.7
13	1	5.5	4.7	2.3	9.4	2.3	0	17.9	0.8	0	1.6	0.8	0.0	7.0
14	2	6.0	2.7	3.3	5.0	0.7	0	8.0	0	1.3	0.7	11.3	11.3	3.3
		0	1.3	2.0	7.3	4.0	0	5.3	0	0	0	2.0	4.7	4.7
15	2	9.5	1.1	1.1	6.3	0	0	2.1	3.2	3.2	0	4.2	4.2	3.2
		12	16	0	16	0	0	12	8	8	0	8	8	4
16	1	5.5	1.6	1.6	7.9	0.8	0	2.4	1.6	0.8	0.8	0	0	0.8
17	1	9.7	0.7	3.5	10.2	2.8	1.4	16.2	1.4	0	0.7	2.8	2.1	2.1
18	2	6.0	1.3	2.0	13.3	0.7	0.7	8.0	0	0	0.7	3.3	3.3	3.3
		4.7	0.7	0	0.7	0	0	1.3	0	0	0	15.3	0.7	0.7
19	1	4.9	4.9	0.7	1.6	0.7	0	13.3	1.4	1.4	1.4	2.8	2.8	1.4
20	1	8.0	0.7	2.0	12.0	2.0	0	16.0	0.7	0.7	0	2.7	2.7	0
21	4*	0	0.7	2.0	0	0	0	0	0.7	0.7	0	17.3	0	0
		3.8	6.0	3.0	5.3	5.3	0	3.8	1.5	1.5	0	5.3	0	0
		0.9	0	2.7	4.5	0	0.9	4.5	1.8	2.7	0	3.6	0.9	0.9
		0	2.2	0	11.1	6.7	0	6.7	0	0	0	0	4.4	4.4
Median		5.2	2.0	2.0	7.6	1.9	0	8.0	0.7	0.7	0	2.0	2.0	2.7
IQR		6.7	3.2	2.0	4.8	3.2	0.5	6.7	1.5	2.0	0.8	1.3	4.2	3.0

\* SARS-CoV-2 variant B.1.1.7.



**Figure 2** Professional football match in February 2021 with four potentially infectious players being tested positive for SARS-CoV-2 variant B.1.1.7. Football-specific contacts (A) and repetitive PCR testing in both teams up to day 14 post-match, highlighting only SARS-CoV-2-positive test results (B). Solid line arrow, PCR testing of team 1; dashed arrow, PCR testing of team 2. \*Mild COVID-19-related symptoms 2 days post-match. \*\*No match participation.

### Transmission-relevant contacts

During small-sided games in recreational adult and youth football, the time a player spent within a radius of 1.5 m (risk zone) was shorter than 3 s 90% of the time.<sup>29</sup> In a professional football match tracking systems showed that the average exposure time per pair of individuals was 32 s.<sup>1</sup> In a more specific approach based on a video analysis, all transmission-relevant physical contacts that occurred during 50 football matches, both between and within players, were examined.<sup>3</sup> It was concluded that aerosol and droplet producing activities (speaking, shouting, spitting) and direct contacts to mucous membranes are infrequent in football matches. In 2020, the impact of knowledge of SARS-CoV-2 was prevalent among players as evidenced in the German Bundesliga by the fact that crowding during goal celebrations (number of players and duration) was considerably reduced after lockdown, only a short-term effect (as values returned to those before lockdown).<sup>3</sup>

### Methodological considerations and limitations

In professional football, testing using PCR at least two times per week has proven to be a reliable hygiene measure.<sup>30–32</sup> Therefore, in our study, professional players who tested positive for SARS-CoV-2 within 48 hours post-match and had a negative test prior to match or training could be considered infectious. Since our eligibility criteria were designed to include players most likely to transmit the virus, players who tested positive >48 hours after match or training were not considered, as from that time onward viral load is assumed to decrease.<sup>8</sup> Although the mean infection period is limited to several days, virus transmission is theoretically possible up to day 9 of infection.<sup>10,33</sup> Furthermore, no conclusions can be drawn on symptomatic players on the field, as this scenario was prevented by hygiene measures. Nevertheless, peak contagiousness occurs in the presymptomatic phase,<sup>8,34</sup> which was captured by our eligibility criteria. In contrast to professional football, the situation in German amateur and youth football was different, where PCR testing was performed on a voluntary basis (or in response to suspected or positively tested contacts) and not consistently up to 14 days after exposure (maximum incubation period).<sup>6,7</sup> Therefore, it is possible that a specific number of asymptomatic infections, estimated in the general population between 20% and 40% (with children being in the upper range), may not have been detected.<sup>35–37</sup> Nevertheless, amateur and youth players who exhibited COVID-19-related symptoms or were part of

a COVID-19 outbreak within the average incubation period before match or training had a substantial likelihood of being infectious if tested SARS-CoV-2-positive. However, the definition of an infectious period is difficult in case of an occasional detection of RNA without serial testing, since PCR might be positive for up to months past infection.<sup>38</sup> In order to assess the SARS-CoV-2 transmission risk in amateur football as accurately as possible, each club was surveyed for COVID-19-related symptoms for up to 14 days after the match or training. Since it was not always possible to interview all players individually or on a daily basis, responses were often given vicariously through teammates, which may have contributed to reporting bias. For this study, PCR cycle thresholds were not used to estimate contagiousness due to the incalculable variability of cut-off values across different laboratories, areas and nations. Reasons for excluding incomplete data from analysis were unclear or missing information regarding symptom onset and timing of testing (eg, gaps in the memory of players, inaccurate media reports) and incomplete or rejected questionnaires. Importantly, none of the criteria to exclude cases from the analysis has led to a bias in the detection of infections. One limitation at the professional level was potential under-reporting through media search, as some clubs were likely reluctant to publicly report infected players to avoid being subject to recriminations regarding adherence to hygiene measures or social life activities. However, our study did not aim at calculating incidences (in the context of an epidemiological approach) but to identify matches and training sessions with potentially infectious players on the pitch, and therefore our outcome remained unaffected by potential under-reporting. Furthermore, press releases from professional clubs on infected players occurred in the majority of cases within 48 hours after match or training session, indicating time of testing and symptom onset were reliable (and not misreported) when applying our eligibility criteria. In the remaining cases, press releases from clubs were only slightly delayed. However, interviews with team physicians confirmed the accuracy of media information (feasible in a quarter of cases). It should be noted that our study ended 2 months before the WHO classified the highly transmissible Delta variant (B.1.617.2) as a variant of concern in May 2021, when it became increasingly prevalent worldwide.<sup>39</sup> Therefore, our findings may have limited transferability to the Delta variant.

## Comparability with the literature and other populations

Previous observational studies on transmission risk of SARS-CoV-2 in football involved regular PCR testing in a defined area and during a specified period, investigating a homogeneous population (professional or youth players), thus allowing comparison with other populations.<sup>18 30 31</sup> In contrast, our study included cases from 14 countries with various incidence rates, different observational periods (3 months for lower league teams vs 8 months for professional teams) and incomplete PCR testing at the amateur and youth level. Therefore, comparisons on a scaled population level are limited. Given the above and the number of only two possible transmission events found in our study, a power calculation was not feasible.

## CONCLUSIONS

In both football matches and training, the on-field transmission risk of SARS-CoV-2 is very low throughout amateur, youth and professional football (based on data from a nationwide registry). The findings are supported by a comprehensive video analysis, PCR testing and symptom monitoring and are consistent with the observation that virus transmission is much lower outdoors than indoors.<sup>16 40</sup> Physical contacts of SARS-CoV-2-positive players during football matches occurred infrequently and were of short duration, thus indicating that proximity to other players does not appear to be sufficient for virus transmission. Sources of infection among football players were found in the private and occupational environment, which should be taken into account when there will be a restart of training and competition.

### What are the findings?

- ▶ In 104 matches and training sessions in amateur, youth and professional football with 165 potentially infectious SARS-CoV-2-positive players, the on-field transmission risk is very low.
- ▶ Video analysis of 21 matches with 34 potentially infectious players revealed that football-specific contacts were not sufficient to transmit the virus, including the SARS-CoV-2 variant B.1.1.7.
- ▶ Infections in football players occurred during non-football activities.

### How might it impact on clinical practice in the future?

- ▶ Outdoor football activities are very low risk and should be considered a safe option for sport and recreation during the COVID-19 pandemic.
- ▶ For the resumption of training and competition, hygiene measures should be implemented to reduce private and occupational sources of infections that occur off the field of play.

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**Competing interests** TM is Chairman of the Medical Committee of the DFB and UEFA. BG is member of the task force 'Sports Medicine/Special Match Operations' of the German Football League (DFL, Deutsche Fußball Liga).

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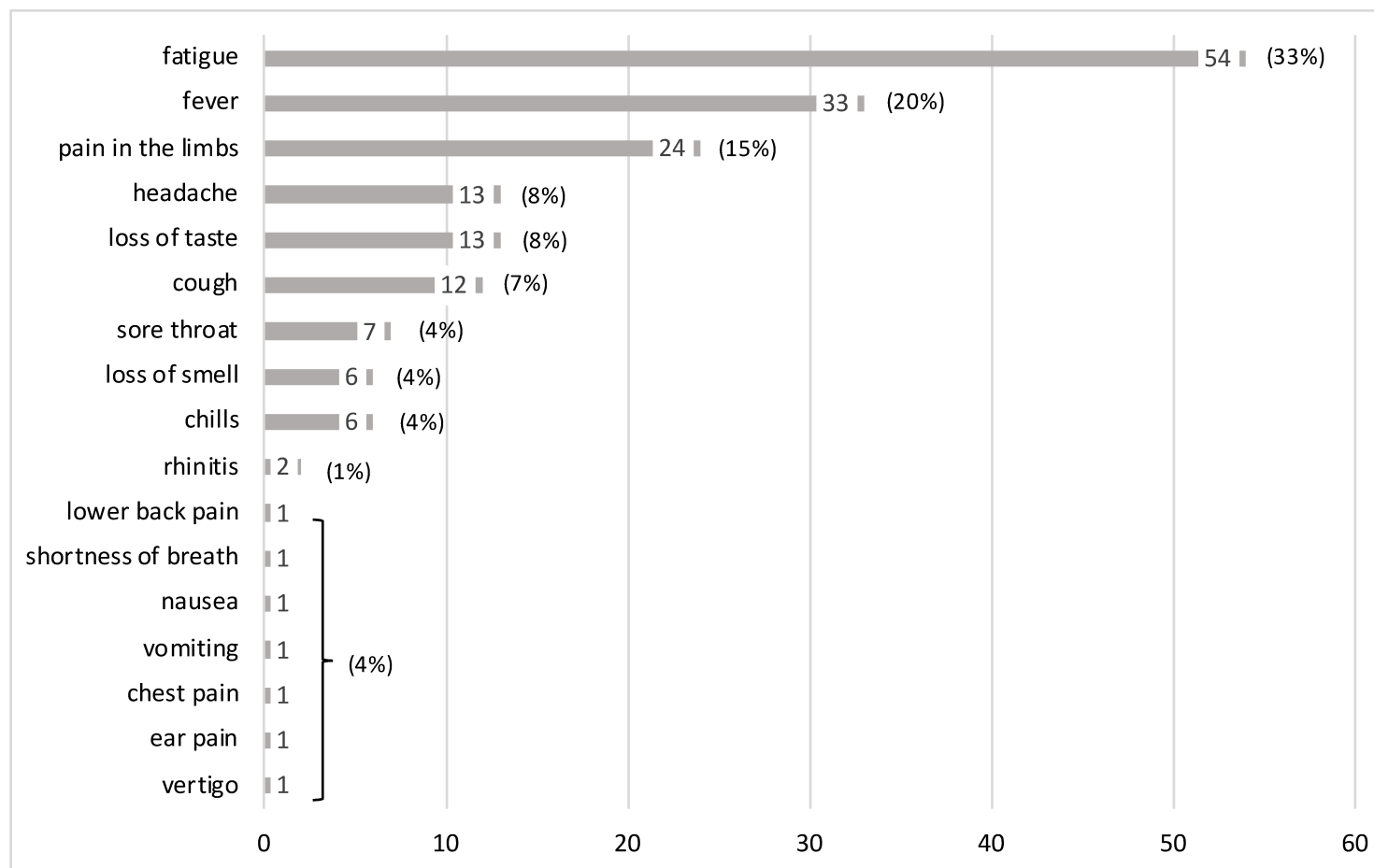
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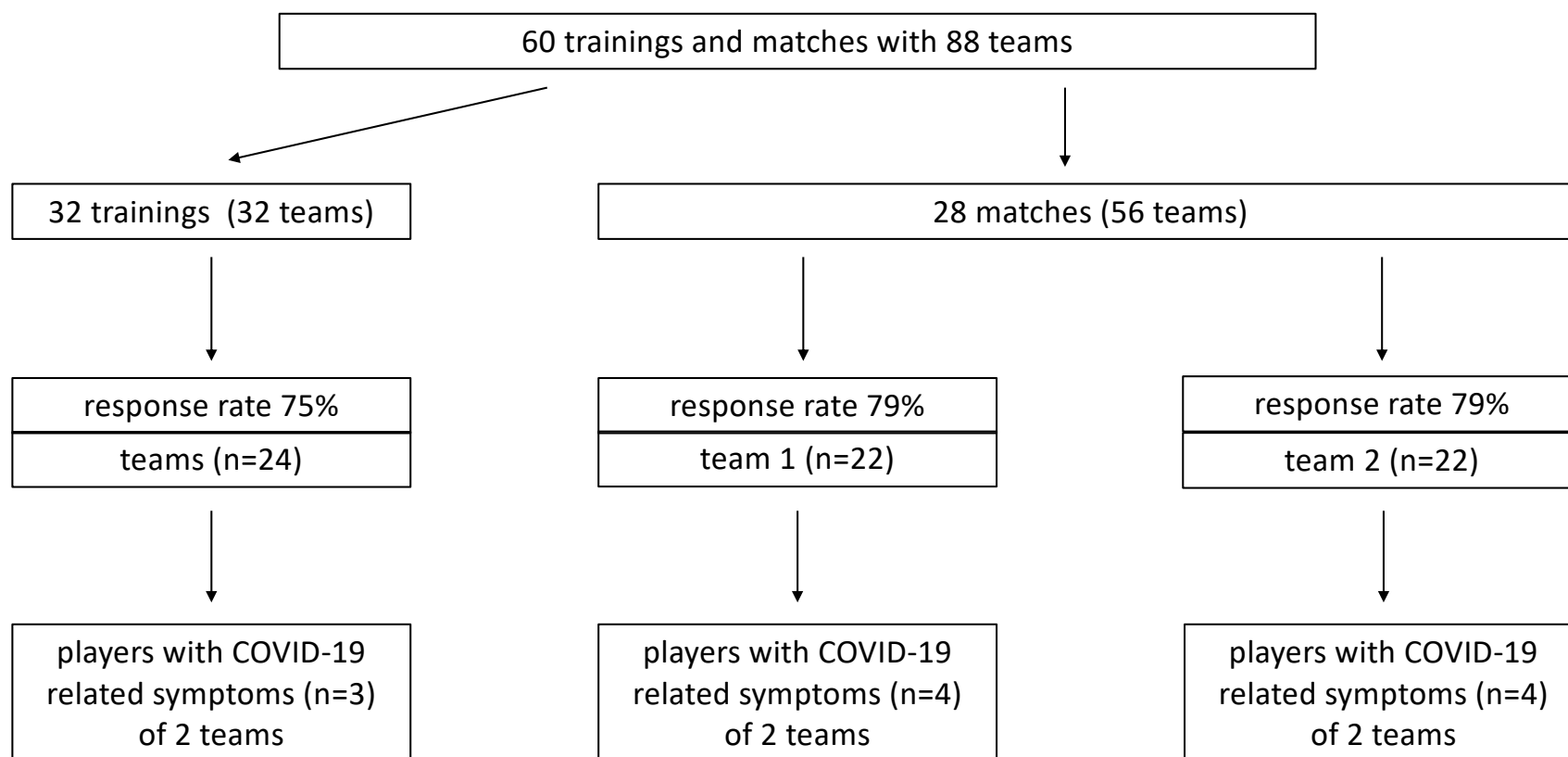
**S1. Report a case of suspected or confirmed SARS-CoV-2 infection in your club**

1. Your regional chapter
2. Club name
3. Team
  - Senior (male)
  - Senior (female)
  - Youth (male)
  - Youth (female)
4. Name of the person reporting
5. Telephone number of the person reporting
6. E-mail address of the person reporting or E-mail address of the club
7. I agree that Saarland University is allowed to contact me for further details on this specific case
  - Yes
  - No
8. Do you report a confirmed or suspected case of SARS-CoV-2 infection?
  - Confirmed case (already tested)
  - Suspected case (results are pending)
  - Suspected case (no testing provided)
9. When did the nasal/oral swab take place?
10. Did you show typical symptoms of SARS-CoV-2 infection (fever, cough, sore throat, headache, aching limbs, fatigue, loss of smell, loss of taste, chills, rhinitis, others)?
  - Yes
  - No
11. Which symptoms occurred (fever, cough, sore throat, headache, aching limbs, fatigue, loss of smell, loss of taste, chills, rhinitis, others)?

12. When did the symptoms occur?
13. Did you have direct contact (match, training, free time) with others associated with the team or with individuals appeared to be ill?
  - Yes
  - No
14. How, when and where did this direct contact take place?
15. Did this direct contact last for longer than 15 minutes?
  - Yes
  - No
16. Was there an opposing team?
  - Yes
  - No
17. Name of the opposing team
18. Which health authority was responsible?
19. What measures have been taken by the responsible health authority (individual quarantine, team quarantine, wait-and-watch strategy, others)?
20. Additional comments

**S2. Football players (n=62) with COVID-19 related symptoms ( $\geq 2$  per player) during the acute phase of the disease.**

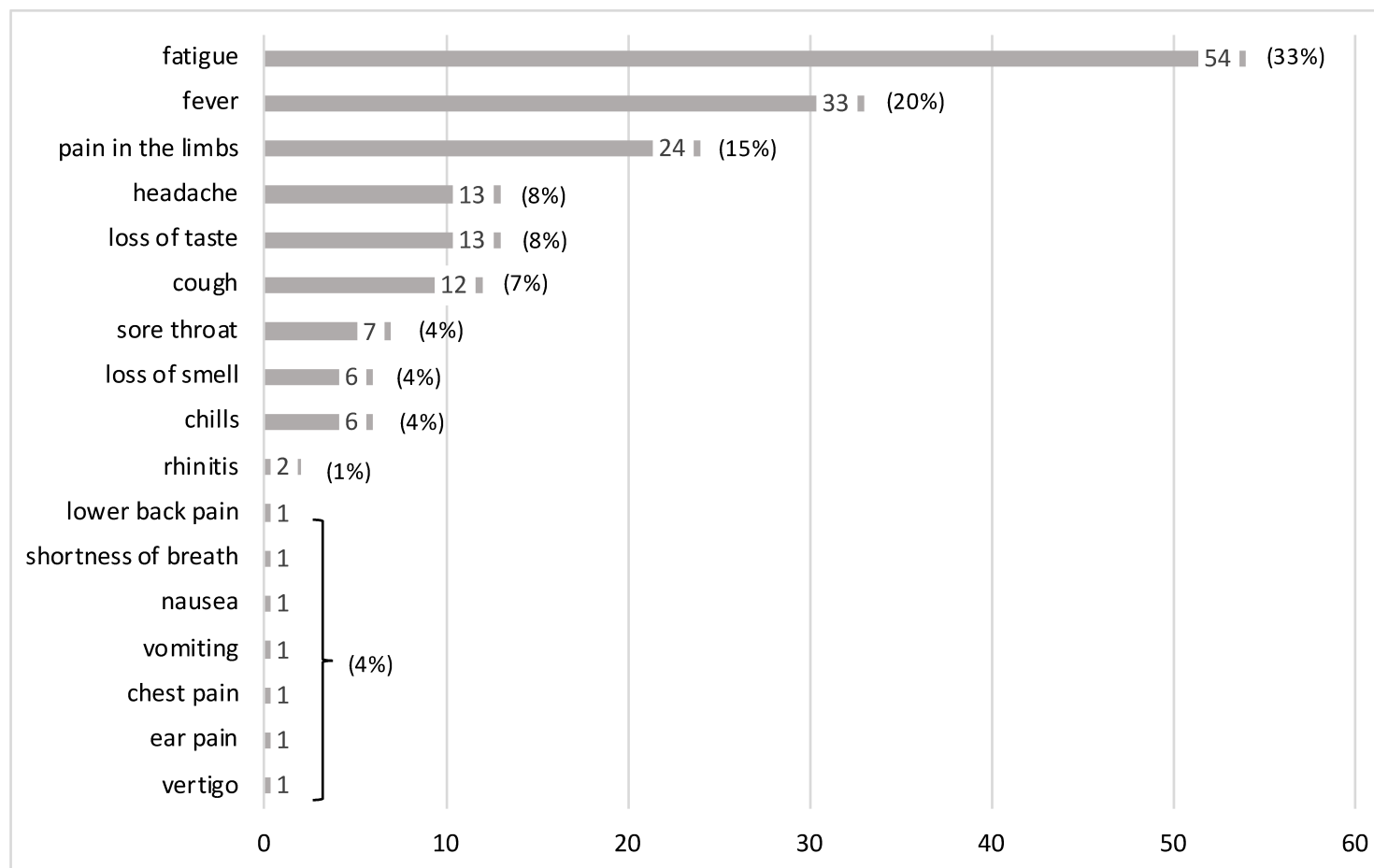
(%) percentage of 165 potentially infectious football players

**S3. Symptom monitoring of exposed players within 14 days after match or training in amateur football.**

**S1. Report a case of suspected or confirmed SARS-CoV-2 infection in your club**

1. Your regional chapter
2. Club name
3. Team
  - Senior (male)
  - Senior (female)
  - Youth (male)
  - Youth (female)
4. Name of the person reporting
5. Telephone number of the person reporting
6. E-mail address of the person reporting or E-mail address of the club
7. I agree that Saarland University is allowed to contact me for further details on this specific case
  - Yes
  - No
8. Do you report a confirmed or suspected case of SARS-CoV-2 infection?
  - Confirmed case (already tested)
  - Suspected case (results are pending)
  - Suspected case (no testing provided)
9. When did the nasal/oral swab take place?
10. Did you show typical symptoms of SARS-CoV-2 infection (fever, cough, sore throat, headache, aching limbs, fatigue, loss of smell, loss of taste, chills, rhinitis, others)?
  - Yes
  - No
11. Which symptoms occurred (fever, cough, sore throat, headache, aching limbs, fatigue, loss of smell, loss of taste, chills, rhinitis, others)?

12. When did the symptoms occur?
13. Did you have direct contact (match, training, free time) with others associated with the team or with individuals appeared to be ill?
  - Yes
  - No
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  - Yes
  - No
16. Was there an opposing team?
  - Yes
  - No
17. Name of the opposing team
18. Which health authority was responsible?
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20. Additional comments

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(%) percentage of 165 potentially infectious football players

### S3. Symptom monitoring of exposed players within 14 days after match or training in amateur football.

