Several studies report high effectiveness of COVID-19 vaccines against SARS-CoV-2 infection and severe disease, however an important knowledge gap is the vaccine effectiveness against transmission (VET). We present estimates of the VET to household and other close contacts in the Netherlands, from February to May 2021, using contact monitoring data. The secondary attack rate among household contacts was lower for fully vaccinated than unvaccinated index cases (11% vs 31%), with an adjusted VET of 71% (95% confidence interval: 63–77).

An important question when making prognoses of the pandemic in the near future and of the need on non-pharmaceutical control measures is to what extent the vaccines reduce the likelihood of transmission from infected vaccinees. Based on routine contact monitoring data, we here estimate the vaccine effectiveness against transmission (VET) and the vaccine effectiveness against infection (VE) among household and other close contacts of confirmed cases of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection in the Netherlands, between 1 February and 27 May 2021. The Alpha variant (Phylogenetic Assignment of Named Global Outbreak (Pango) lineage designation B.1.1.7) was the dominant variant in the area at that time.

Source and contact tracing
In the Netherlands, people are encouraged to undergo SARS-CoV-2 testing free of charge when experiencing symptoms or after contact with a confirmed case [1]. Infections confirmed by PCR, loop mediated isothermal amplification (LAMP) or antigen test are notified to the regional Municipal Health Services (MHS), who perform source and contact tracing and contact monitoring [2]. During our study period, household members and other close contacts of confirmed cases needed to quarantine for 10 days post exposure. All close contacts of a confirmed case were encouraged to get tested as soon as possible after exposure. In addition, a test was recommended on the 5th day after last exposure. If negative, contacts could end quarantine. We obtained a pseudonymised minimal contact monitoring dataset from all MHS. Additional data on index cases and contacts who tested positive, including the vaccine received and date of symptom onset, was extracted from the national infectious disease notification registry. Of note, a contact becomes an index case when testing positive, so our study could include some persons both as contact and as index case.

Vaccination status
The time since vaccination of the index case was based on the number of days between vaccination and a date used for statistics (DUFS), which was either the reported date of symptom onset or, if that was unknown, the date of positive test result minus 2 days. For vaccinated contacts, time since vaccination was calculated as the number of days between vaccination and the date of first exposure of the contact to the index case within the infectious period of the index, which is defined during source and contact tracing as 2 days before symptom onset or 2 days before test. Partly vaccinated
was defined as having received the first dose of a two-dose coronavirus disease (COVID-19) vaccine, with a time since vaccination of at least 14 days. Fully vaccinated was defined as having completed a two-dose schedule with a time since vaccination of at least 7 days, or the one-dose Janssen (Ad26.COV2-S (recombinant), Janssen-Cilag International NV, Beerse, Belgium) schedule with a time since vaccination of at least 14 days. We included only index cases aged 18 years or older because children were not eligible for vaccination at the time. Contacts aged 0–17 years were included in the VET analyses, but not in the VE analyses. In order to exclude co-primary cases, the household contacts of an index were excluded if the most likely setting of infection of the index was ‘at home’ according to the source tracing interview (excluding 44,676 contacts (15%)). Further, only SARS-CoV-2-positive contacts with a DUFS within 1 to 14 days after the DUFS of the index case were included in the analyses, to reduce misclassification of indexes and secondary cases.

### Table 1
Characteristics of COVID-19 index cases (18 years and older), by vaccination status of the index and characteristics of contacts, and by vaccination status of the contact, the Netherlands, 1 February–27 May 2021 (n = 113,582 index cases, n = 253,168 contacts)

| Vaccination status index | Unvaccinated | Partially vaccinated | Fully vaccinated | Unvaccinated | Partially vaccinated | Fully vaccinated |
|--------------------------|--------------|---------------------|-----------------|--------------|---------------------|-----------------|
| n | % | n | % | n | % | n | % | n | % | n | % |
| Total | 110,872 | 2,088 | 622 | 243,360 | 4,411 | 5,397 |
| Number of contacts by type | | | | | | |
| Household | 139,802 | 56 | 2,032 | 50 | 706 | 55 | 138,095 | 57 | 1,917 | 43 | 2,528 | 47 |
| Other close contacts | 108,041 | 44 | 2,004 | 50 | 583 | 45 | 105,265 | 43 | 2,494 | 57 | 2,869 | 53 |
| Sex | | | | | | |
| Female | 56,554 | 51 | 1,325 | 63 | 472 | 76 | 121,183 | 50 | 2,689 | 61 | 4,139 | 77 |
| Male | 54,318 | 49 | 763 | 37 | 150 | 24 | 120,473 | 50 | 1,684 | 38 | 1,216 | 23 |
| Unknown/other | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,704 | 1 | 38 | 1 | 42 | 1 |
| Age (years) | | | | | | |
| 0–11 | 0 | 0 | 0 | 0 | 0 | 0 | 42,119 | 17 | 0 | 0 | 0 | 0 |
| 12–17 | 0 | 0 | 0 | 0 | 0 | 0 | 19,770 | 8 | 0 | 0 | 0 | 0 |
| 18–29 | 31,736 | 29 | 209 | 10 | 122 | 20 | 57,264 | 24 | 437 | 10 | 961 | 18 |
| 30–49 | 42,142 | 38 | 347 | 17 | 179 | 29 | 54,591 | 22 | 562 | 13 | 1,102 | 20 |
| 50–74 | 34,383 | 31 | 1,155 | 55 | 194 | 31 | 58,688 | 24 | 2,688 | 61 | 2,280 | 42 |
| ≥ 75 | 2,611 | 2 | 377 | 18 | 127 | 20 | 4,321 | 2 | 724 | 16 | 1,054 | 20 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 6,607 | 3 | 0 | 0 | 0 | 0 |
| Vaccine received | | | | | | |
| Vaxzevria | NA | 1,144 | 55 | 35 | 6 | NA | 2,127 | 48 | 407 | 8 |
| Comirnaty | NA | 890 | 43 | 530 | 85 | NA | 1,235 | 28 | 3,312 | 61 |
| Janssen | NA | 0 | 0 | 21 | 3 | NA | 0 | 0 | 83 | 2 |
| Spikevax | NA | 54 | 3 | 36 | 6 | NA | 86 | 2 | 247 | 5 |
| Unknown | NA | 0 | 0 | 0 | 0 | NA | 963 | 22 | 1,348 | 25 |
| Household composition | | | | | | |
| Couple with children | 12,782 | 15 | 117 | 8 | 61 | 14 | 34,603 | 25 | 126 | 7 | 286 | 11 |
| Couple without children | 33,096 | 40 | 809 | 58 | 181 | 43 | 32,264 | 23 | 908 | 47 | 914 | 36 |
| Households with > two adults | 21,459 | 26 | 272 | 19 | 112 | 27 | 55,408 | 40 | 648 | 34 | 1,062 | 42 |
| Other | 16,056 | 19 | 197 | 14 | 68 | 16 | 15,820 | 11 | 235 | 12 | 266 | 11 |
| Month of notification date of the index case | | | | | | |
| Feb | 29,953 | 27 | 196 | 9 | 43 | 7 | 62,213 | 26 | 182 | 4 | 374 | 7 |
| Mar | 38,573 | 35 | 435 | 21 | 163 | 23 | 88,116 | 36 | 738 | 17 | 1,571 | 29 |
| Apr | 20,648 | 19 | 448 | 21 | 151 | 24 | 45,977 | 19 | 919 | 21 | 1,252 | 23 |
| May | 21,698 | 20 | 1,009 | 48 | 285 | 46 | 47,054 | 19 | 2,572 | 58 | 2,000 | 41 |

COVID-19: coronavirus disease; NA: not applicable.

* Column percentage.

| Household composition | Couple with children | Couple without children | Households with > two adults | Other |
|-----------------------|-----------------------|-------------------------|-------------------------------|-------|
| n | % | n | % | n | % | n | % |
| 12,782 | 15 | 33,096 | 40 | 21,459 | 26 | 16,056 | 19 |
| 117 | 8 | 809 | 58 | 272 | 19 | 197 | 14 |

| Month of notification date of the index case | Feb | Mar | Apr | May |
|------------------|----------|----------|----------|----------|
| n | % | n | % | n | % | n | % |
| 29,953 | 27 | 38,573 | 35 | 20,648 | 19 | 21,698 | 20 |
| 196 | 9 | 435 | 21 | 448 | 21 | 1,009 | 48 |

Index cases and contacts
The final dataset contained 253,168 contacts of 113,582 index cases (5,394 persons in our study were both contact and index case). Of the index cases, 622 (0.5%) were fully vaccinated and 2,088 (1.8%) were partly vaccinated. Of the contacts, 5,397 (2.1%) were fully vaccinated and 4,411 were partly vaccinated (1.7%). Characteristics of indexes and contacts are shown in Table 1. We calculated the VET via the secondary attack rate (SAR) among close contacts of confirmed index cases: 1 − (SAR\_vaccinated\_index / SAR\_unvaccinated\_index) × 100% [3]. The VE among contacts was calculated as: 1 − (AR\_vaccinated\_contacts / AR\_unvaccinated\_contacts)
Crude attack rate of SARS-CoV-2 among contacts, by vaccination status of the index (left to right) and vaccination status of the contact (top to bottom), the Netherlands, 1 February–27 May 2021 (n = 113,582 index cases, n = 253,168 contacts)

SARS-CoV-2: severe acute respiratory syndrome coronavirus 2.

The n subtotals in the panels indicate the number of unvaccinated/partly vaccinated/fully vaccinated household and other close contacts of unvaccinated/partly vaccinated/fully vaccinated index cases. For example, n=604 in the upper left panel denotes that fully vaccinated index cases had 604 unvaccinated household contacts.
Table 2
Secondary attack rate of SARS-CoV-2 by vaccination status of the index case (≥ 18 years) and vaccine effectiveness against transmission\(^a\), crude and adjusted for age group of the index case\(^b\) and contact\(^c\) and for vaccination status\(^d\) of contacts and month of notification date of the index case, the Netherlands, 1 February−27 May 2021 (n = 113,582 index cases, n = 253,168 contacts)

| Analysis                        | Unvaccinated index - SAR | Partly vaccinated index - SAR | Fully vaccinated index - SAR |
|---------------------------------|--------------------------|-------------------------------|-----------------------------|
|                                 | Positive | Total | % | Positive | Total | % | Positive | Total | % | Positive | Total | % |
| Household contacts              |          |       |   |          |       |   |          |       |   |          |       |   |
|                                 | 43,069   | 139,802 | 31 | 587      | 2,032 | 29 | 9        | (−1 to 17) | 21 | 12 to 28 | 79 | 706 | 11 | 72 | 65 to 78 | 71 | 63 to 77 |
| Household contacts - unvaccinated only | 42,382   | 135,974 | 31 | 432      | 1,517 | 28 | 12       | (11 to 21) | 23 | 14 to 32 | 68 | 604 | 11 | 73 | 64 to 79 | 73 | 65 to 79 |
| Other close contacts            | 11,395   | 108,041 | 11 | 193      | 2,004 | 10 | 11       | (−4 to 23) | 22 | 9 to 33  | 50 | 583 | 9  | 22 | (−5 to 43) | 22 | (−5 to 43) |
| Other close contacts - unvaccinated only | 11,115   | 103,123 | 11 | 171      | 1,680 | 10 | 7        | (−9 to 21) | 22 | 8 to 34  | 44 | 462 | 10 | 14 | (−18 to 37) | 24 | (−5 to 45) |
| Household contacts - Vaxzevria   | 43,069   | 139,802 | 31 | 364      | 1,306 | 28 | 13       | (1 to 23)  | 15 | 4 to 26  | 5  | 39  | NP | 67 | 61 to 87 | 58 | (−12 to 84) |
| Household contacts - Comirnaty   | 43,069   | 139,802 | 31 | 211      | 663  | 32 | −4       | (−22 to 12) | 26 | 12 to 37 | 70 | 596 | 12 | 71 | 62 to 77 | 70 | (61 to 77) |
| Household contacts - Spikevax    | 43,069   | 139,802 | 31 | 12       | 63   | NP | 46       | (−3 to 71) | 51 | 8 to 74  | 2  | 40  | NP | 88 | 51 to 97 | 88 | (50 to 97) |
| Household contacts - Janssen     | 43,069   | 139,802 | 31 | NA       | NA   | NA | 2        | 31 NP      | 85 | 37 to 96 | 77 | (6 to 94) |

CI: confidence interval; GEE: generalised estimating equations; NA: not applicable; NP: not presented; SAR: secondary attack rate; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2; VET: vaccine effectiveness against transmission.

\(^a\) VET estimated by GEE with exchangeable correlation structure.

\(^b\) Age groups index cases: 18−29, 30−49, 50−74, ≥75 years.

\(^c\) Age groups contacts: 0−17, 18−59, ≥60 years.

\(^d\) Vaccination status of contacts: unvaccinated, partly or fully vaccinated.

Partly vaccinated was defined as having received the first dose of a two-dose schedule at least 14 days before onset of symptoms. Fully vaccinated was defined as having completed a two-dose schedule at least 7 days or the one-dose Janssen schedule at least 14 days before symptom onset. Only percentages based on denominators above 100 are presented, please note the VET estimates based on smaller numbers are less precise.
| Analysis                                      | Unvaccinated contacts - AR | Partly vaccinated contacts - AR | Partly vaccinated contacts - crude VE (95% CI) | Partly vaccinated contacts - adjusted VE (95% CI) | Fully vaccinated contacts - AR | Fully vaccinated contacts - crude VE (95% CI) | Fully vaccinated contacts - adjusted VE (95% CI) |
|----------------------------------------------|-----------------------------|---------------------------------|------------------------------------------------|-------------------------------------------------|---------------------------------|-----------------------------------------------|-----------------------------------------------|
| Household contacts                           | 32,086                      | 91,528                          | 35 % 573                                         | 1,917                                          | 30 % 21 (13 to 28) enumeration | 23 (14 to 30)                           | 280                                          | 2,528                                          | 11 % 76 (73 to 79) enumeration | 75 (72 to 78)                           |
| Household contacts - only unvaccinated index  | 31,694                      | 90,066                          | 35 % 432                                         | 1,508                                          | 29 % 25 (17 to 33) enumeration | 26 (17 to 34)                           | 255                                          | 2,320                                          | 11 % 77 (74 to 79) enumeration | 76 (73 to 79)                           |
| Other close contacts                          | 9,883                       | 81,336                          | 12 % 231                                         | 2,494                                          | 9 % 24 (13 to 34) enumeration | 28 (17 to 37)                           | 77                                           | 2,869                                          | 3 % 79 (74 to 83) enumeration | 79 (74 to 83)                           |
| Other close contacts - only unvaccinated index| 9,699                       | 81,666                          | 12 % 210                                         | 2,257                                          | 9 % 24 (12 to 34) enumeration | 27 (15 to 37)                           | 70                                           | 2,661                                          | 3 % 79 (74 to 84) enumeration | 80 (74 to 84)                           |
| Household contacts - Vaxzevria                | 32,086                      | 91,528                          | 35 % 356                                         | 1,052                                          | 34 % 5 (−8 to 16) enumeration | 2 (−11 to 14)                           | 11                                           | 186                                          | 6 % 88 (78 to 93) enumeration | 87 (77 to 93)                           |
| Household contacts - Comirnaty                | 32,086                      | 91,528                          | 35 % 194                                         | 467                                            | 42 % −30 (−56 to −8) enumeration | −18 (−43 to 2)                           | 242                                          | 1,605                                          | 15 % 67 (62 to 71) enumeration | 65 (60 to 70)                           |
| Household contacts - Spikevax                 | 32,086                      | 91,528                          | 35 % 11                                          | 48 NP                                          | 42 % 45 (−5 to 71) enumeration | 33 (−27 to 64)                           | 4                                            | 121                                          | 3 % 93 (83 to 97) enumeration | 91 (79 to 97)                           |
| Household contacts - Janssen                  | 32,086                      | 91,528                          | 35 % 11                                          | 48 NP                                          | 42 % 45 (−5 to 71) enumeration | 33 (−27 to 64)                           | 4                                            | 121                                          | 3 % 93 (83 to 97) enumeration | 91 (79 to 97)                           |

AR: attack rate; CI: confidence interval; GEE: generalised estimating equations; NA: not applicable; NP: not presented; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2; VE: vaccine effectiveness.

*VE estimated by GEE with exchangeable correlation structure.
*Age groups index cases: 18–29, 30–49, 50–74, ≥75 years.
*Age groups contacts: 0–17, 18–59, ≥60 years.
*Vaccination status of contacts: unvaccinated, partly or fully vaccinated.

Only contacts 18 years and older were included. Partly vaccinated was defined as having received the first dose of a two-dose schedule at least 14 days before onset of symptoms. Fully vaccinated was defined as having completed a two-dose schedule at least 7 days or the one-dose Janssen schedule at least 14 days before symptom onset. Only percentages based on denominators above 100 are presented, please note the VE estimates based on smaller numbers are less precise.
binomial generalised linear model. For parameter fit-
ing we used the generalised estimating equations
approach with exchangeable correlation structure to
account for clustering of contacts belonging to the
same index case [4].

Vaccine effectiveness against transmission
The Figure shows the crude attack rates among
contacts, in relation to the vaccination status of both
index and contact. The SAR was 31% among household
contacts of unvaccinated index cases and 11% among
household contacts of fully vaccinated index cases
(Table 2). Adjusting for age of the index and contact,
vaccination status of the contact and month of noti-
fication date of the index case, the VET to household
contacts after full vaccination was 71% (95% confi-
dence interval (CI): 63 to 77). The VET to other close
contacts was much lower (22%; 95% CI: −5 to 43),
probably because of the larger risk of the contact being
infected through another source (i.e. misclassifica-
tion of the index case). Stratified by vaccine received
by the index case, VET values were estimated at 58%
for Vaxzevria (ChAdOx1-S; AstraZeneca, Cambridge,
United Kingdom), 70% for Comirnaty (BNT162b2; BioNtech/Pfizer, Mainz, Germany/New York, United
States (US)), 88% for Spikevax (mRNA-1273, Moderna,
Cambridge, US) and 77% for the Janssen vaccine.
For all vaccines with a two-dose schedule, the adjusted
VET (aVET) after one dose was considerably lower than
after two doses: 15% for Vaxzevria, 26% for Comirnaty
and 51% for Spikevax (Table 2).

Vaccine effectiveness among contacts
The adjusted VE (aVE) for fully vaccinated household
contacts of confirmed cases was estimated at 75%
(95% CI: 72 to 78) and for fully vaccinated other close
contacts at 79% (95% CI: 74 to 83) (Table 3). Stratified
by the vaccine received by the contact, aVE was 87%
for Vaxzevria, 65% for Comirnaty, 91% for Spikevax
and 12% for Janssen’s vaccine. Note that the estimate
for the Janssen vaccine was based on only 44 vacci-
nated contacts, with a median time since vaccination
of 21 days. The proportion of vaccinated contacts with
unknown vaccine manufacturer was large (Table 1),
which reduces the power of the analyses stratified by
vaccine.

Discussion
We estimated a VET of 71% among household contacts
of fully vaccinated index cases. Harris et al. found a
VET of 40–50% for unvaccinated households contacts
[5]. That study mostly included partly vaccinated index
cases. A study among household contacts of health-
care workers by Shah et al. found a 30% (after the first
dose) and 64% (after the second dose) reduction in the
risk of confirmed SARS-CoV-2 infection among house-
hold members of vaccinated healthcare workers, how-
ever these healthcare workers were not confirmed as
index cases [6].

Martínez-Baz et al. recently estimated VE among
20,961 close contacts of confirmed cases in Spain [7].
In that study, the VE for two doses of Comirnaty was
65% (95% CI: 56 to 73) against infection, which is in
agreement with our finding of 65% VE for this vaccine.
These estimates are lower than VE from other observa-
tional post-marketing studies. Possibly, the VE against
infection is lower when there is high and prolonged
exposure to SARS-CoV-2, which is likely for household
contacts of confirmed cases [8]. Of note, Martínez-Baz
et al. showed an aVE for Comirnaty of 94% (95% CI: 60
to 99) against hospitalisation among close contacts of
confirmed cases.

As our study used data not primarily collected for
research purposes, it has some important limitations.
Our data do not contain information on negative tests
among contacts, therefore we do not know if contacts
did not get infected or did not seek testing. However,
it is likely that close contacts were tested regardless
of vaccination status, as the quarantine period for
close contacts at the time was reduced from 10 to 5
days when tested negative on day 5 after exposure. For
contacts who tested positive, data on vaccination sta-
tus were more complete because missing data could
be supplemented from the notifications. We explored
whether this differential completeness influenced our
results by excluding all index cases with any house-
hold contact with unknown vaccination status or date
of vaccination, and the results were the same (data not
shown).

Although we tried to minimise misclassification of
indexes and contacts by excluding index cases infected
at home and contacts with symptom onset before or
at the same time as the index, it is plausible that in
some instances, the transmission route was reversed
or transmission occurred through another source (espe-
cially for non-household contacts). If some contacts
of vaccinated index cases were infected through other
sources, our VET is an underestimation. In addition,
we do not have reliable data on the symptoms of the
included index cases. Because our analysis on house-
hold contacts was restricted to notified index cases
not infected at home, probably most of these index
cases sought testing because they had symptoms.
Symptomatic cases may have been misclassified as
index cases in a household, where in reality an asympto-
matic household member was the source of transmis-
sion to the supposed index case and a third household
member. If vaccinees are more likely to be asymptom-
atic, this source of misclassification may result in an
overestimation of the VET.

As the Alpha variant of SARS-CoV-2 dominated
during the study period, an important question is to what
extent these VET and VE estimates hold in the con-
text of the Delta variant (Pango lineage designation
B.1.617.2) which is now dominant in the Netherlands.
Also, further research is needed to determine whether
the observed differences between the different
Conclusion

Our study showed that the COVID-19 vaccines not only protect the vaccinee against SARS-CoV-2 infection, but also offer protection to transmission to close contacts after completing the full schedule. This finding underscores the importance of full vaccination of close contacts of vulnerable persons.

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Conflict of interest

None declared.

Authors’ contributions

Study design: Brechje de Gier, Stijn Andeweg, Jan van de Kassteele, Mirjam Knol. Data collection, management and quality control: Rosa Joosten, Ronald ter Schegget, Stijn Andeweg, Naomi Smorenburg, the RIVM COVID-19 surveillance and epidemiology team. Data analysis: Brechje de Gier, Stijn Andeweg. Interpretation of the data: Brechje de Gier, Stijn Andeweg, Susan Hahné, Susan van den Hof, Hester de Melker, Mirjam Knol. Manuscript draft: Brechje de Gier. All authors critically revised the manuscript and approved the final manuscript.

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