How do contact patterns affect VOC transmission advantage?

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Mechanistic modelling of increased transmissibility

The transmission advantage of different viral variants is typically modelled as a multiplicative scaling of the reproduction number, R. Here we show that this is likely an overly simplistic representation.

Let us crudely decompose R into a product of number of contacts made over the course of infectiousness, c, and the probability of infection per contact, p: $R = cp$. The probability p can be further represented as a function of instantaneous infectiousness b (the hazard of infection per person per unit time of contact) and the duration of contact, T: $p = 1 - e^{-bT}$.

Increased infectiousness is likely to biologically manifest as a multiplicative increase in b, not directly in p or R. Let x represent the increase in b due to the VOC, such that the probability of infection per contact for the variant is $p' = 1 - e^{-xbT} = 1 - (1 - p)^x$. Defining $R' = cp'$ to be the reproduction number of the variant, the transmission advantage of the variant is $R'/R = [1 - (1 - p)^x]/p$. This tends to x as $p \to 0$ (the large population, random mixing, instantaneous contact limit). One can allow for heterogeneity in the duration of contact by integrating the equation for p' over a distribution for T. Assuming an exponential distribution for the duration of contact gives $R'/R = x/[1 + p(x - 1)]$.

The effect of these network effects is to reduce the observed transmission advantage R'/R as p increases (*i.e.* as social distancing becomes more intense) – see Figure 1.

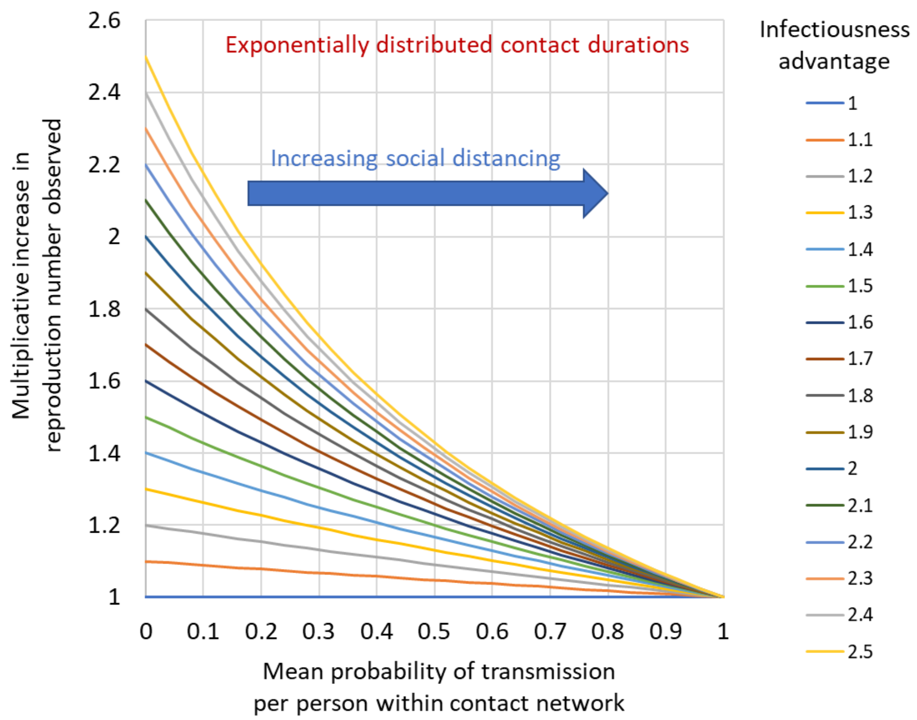

Figure 1: Multiplicative increase in reproduction seen for different intrinsic infectiousness advantages and non-variant probability of transmission per contact.

Interaction with social distancing

In reality, transmission occurs in a combination of low c but high p environments (e.g. households) and ones with high c but lower p (e.g. schools).

Social distancing measures do not just change c but modify the whole $\{c, p\}$ distribution. Typically, intensifying social distancing will reduce c, but will also drive-up average p as transmission between households becomes less common and transmission within households becomes a larger fraction of all transmission.

It is likely that we are seeing this in action with the VOC. During the November lockdown variant transmission was focussed on teenagers in school (lower p, higher c). But over Christmas, c was dramatically reduced and p (for the remaining contacts) increased.

A subtlety of this is that the relevant $\{c, p\}$ distribution is that of the individuals currently infected with the variant (and non-variant) - not that of the whole population. Akin to the next generation matrix, this distribution likely stabilises during periods of exponential growth or decline.

Implications for control and interpreting surveillance trends

We find some evidence (Figure 2) that the reproduction advantage (R'/R) has varied over time for the VOC, with trends differing in different age groups. In particular, the transmission advantage observed in 11-18 year olds was highest in the second England lockdown, when schools were open but contacts between other age groups were curtailed. That age group saw a substantial reduction in the estimated transmission advantage following the start of Christmas holidays (week 52). The all-age and 19+ transmission advantage peaked in week 49-50, coincidence with the end of the second lockdown, and has declined somewhat thereafter, coincident with the intensifying of social distancing measures and the Christmas holidays.

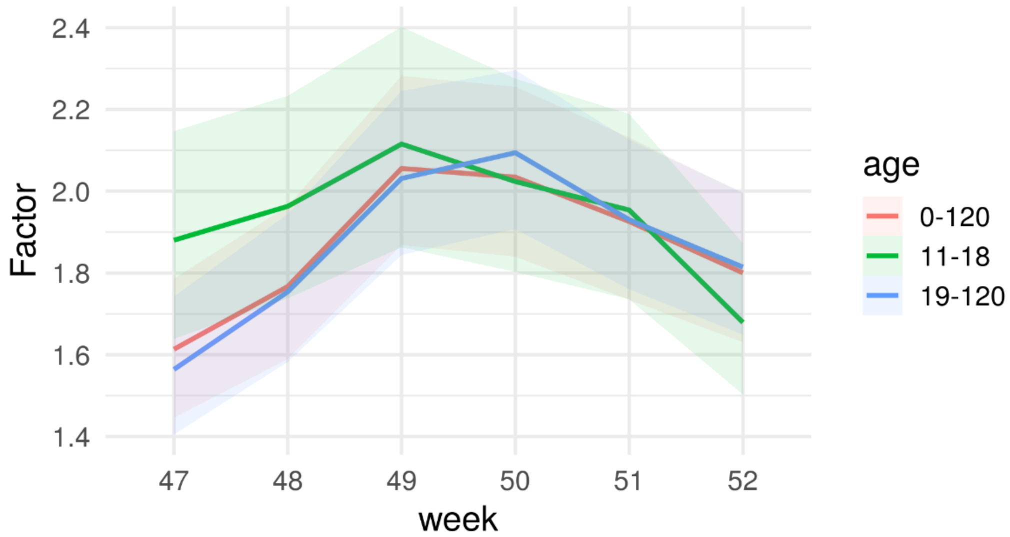

Figure 2: Estimated transmission advantage of VOC vs non-VOC strains from SGTF pillar 2 data, corrected for proportion of pillar 2 cases with S-gene results. Transmission advantage expressed in terms of week-to-week growth factor of case numbers. Non-linear regression at NHS STP level used, with negative binomial likelihood and random walk prior on the weekly growth factor of non-variant. Estimates before week 47 are not reliable due to lower specificity of SGTF as a proxy for the VOC at earlier time points.

The higher R'/R ratio seen in 11-18 year-olds compared with adults seen during the second lockdown may also explain the transiently higher proportion of VOC cases seen in 11-19 year olds compared with non-VOC cases (especially in weeks 48 and 49), shown in Figure 3.

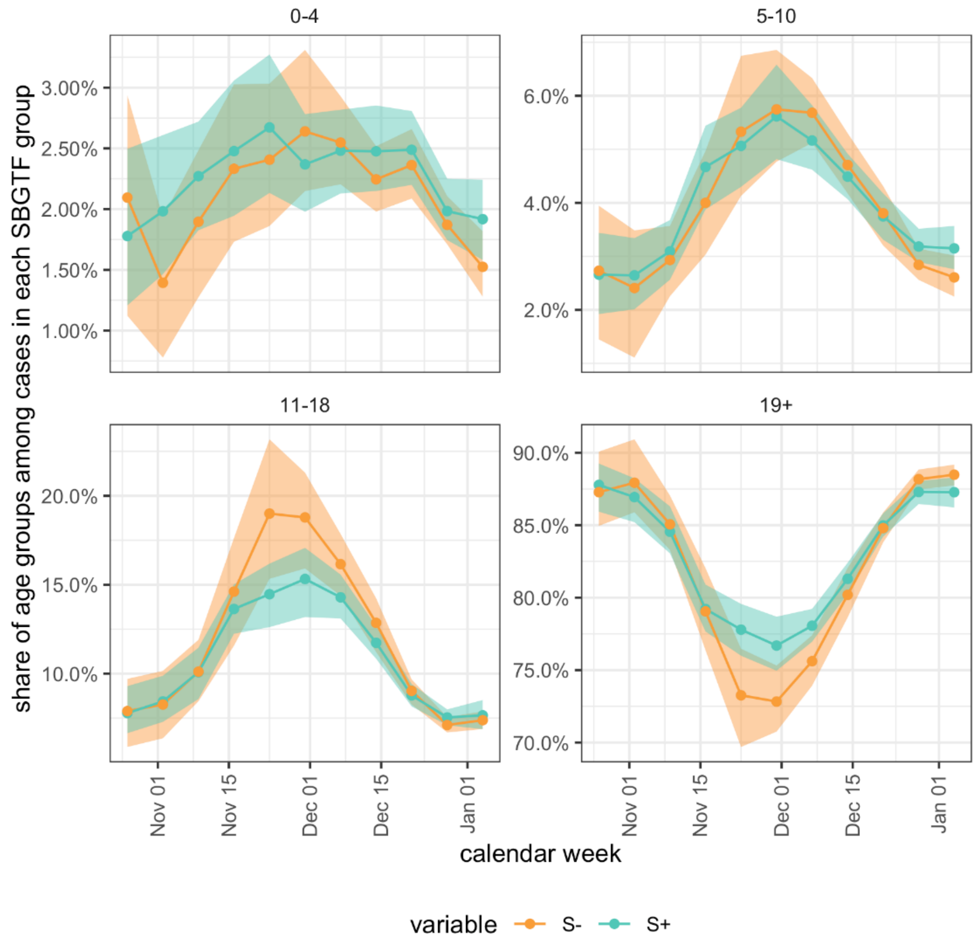

Figure 3: Proportion on VOC and non-VOC cases in different age bands by epidemiological week, calculated using a case-control weighting applied at STP level by week. Bootstrap 95% confidence intervals shown. Raw (unweighted) SGTF data shows the same trends.

The reduction in R'/R seen in recent weeks is positive news for the chance that the third lockdown may achieve $R' < 1$, albeit we are still estimating an over 50% transmission advantage in week-on-week growth factors.

However, this analysis suggests that R' will increase by more than this 50% transmission advantage estimate would suggest when social distancing measures are relaxed. Re-opening secondary schools may pose a particular risk.

More generally, we conclude that the transmission advantage of the variant is likely to vary by context and the nature and frequency of contacts in different settings. The transmission advantage observed is likely to by highest (perhaps 2-fold) in settings where many brief contacts are made, but lowest in settings (such as the household) where a few intense, long duration contacts are made. This is consistent with PHE/TTI data suggesting a ~40% increase in household secondary attack rates seen in household contacts.