



HAL
open science

Characterization of vaccine-breakthrough infections of SARS-CoV-2 Delta and Alpha variants and within-host viral load dynamics in the community in France

François Blanquart, Clémence Abad, Joevin Ambroise, Mathieu Bernard,
Gina Cosentino, Jean-Marc Giannoli, Florence Débarre

► To cite this version:

François Blanquart, Clémence Abad, Joevin Ambroise, Mathieu Bernard, Gina Cosentino, et al.. Characterization of vaccine-breakthrough infections of SARS-CoV-2 Delta and Alpha variants and within-host viral load dynamics in the community in France. 2021. hal-03318483v1

HAL Id: hal-03318483

<https://hal.sorbonne-universite.fr/hal-03318483v1>

Preprint submitted on 10 Aug 2021 (v1), last revised 15 Aug 2021 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Characterization of vaccine-breakthrough infections of SARS-CoV-2 Delta and Alpha variants and within-host viral load dynamics in the community in France

François Blanquart^{1,2 *} Clémence Abad³ Joevin Ambroise⁴
Mathieu Bernard⁵ Gina Cosentino^{4,6} Jean-Marc Giannoli⁷
Florence Débarre^{8 **}

2021-08-03

1. Infection Antimicrobials Modelling Evolution, UMR1137, INSERM, Université de Paris, Paris, France
2. Centre for Interdisciplinary Research in Biology (CIRB), Collège de France, CNRS, INSERM, PSL Research University, Paris, France
3. LBM BIOESTEREL–Biogroup–Plateau technique de Mouans-Sartoux, Mouans-Sartoux, France
4. BPO-BIOEPINE–Biogroup–Plateau technique Chocolaterie, Levallois-Perret, France
5. BIOLITTORAL – Biogroup – Plateau technique la Bastide, Sanary sur Mer, France
6. UMR1173 INSERM, UniversitéParis-Saclay–UVSQ, Montigny-le-Bretonneux, France
7. DYOMEDEA-NEOLAB-Biogroup – Plateau technique de la Sauvegarde, Lyon 9 France
8. Institute of Ecology and Environmental Sciences of Paris (iEES-Paris, UMR 7618), CNRS, Sorbonne Université, UPEC, IRD, INRAE, 75252 Paris, France

*francois.blanquart@college-de-france.fr

**florence.debarre@normalesup.org

1 **Abstract:** We compare test results of SARS-CoV-2 positive patients, depending on their vaccine status,
2 the presence of symptoms and whether they are infected by the Delta variant or not, using a large num-
3 ber of PCR tests done in the community in France from 14 June 2021 to 30 July 2021. In asymptomatic
4 individuals, Ct values at the first positive test were higher in fully vaccinated individuals (> 2 weeks after
5 final dose) than non fully vaccinated individuals (1.7 [1, 2.3], $p < 1e-6$). In *symptomatic* individuals
6 however, Ct values at the time of symptoms were not significantly different in vaccinated compared
7 to unvaccinated individuals ($p = 0.26$). This was true both for infections by Delta and non-Delta
8 (essentially Alpha in France at the time) variants. These results imply that some infected vaccinated
9 individuals, especially if symptomatic, may transmit the virus as much as unvaccinated individuals.

10

11 The SARS-CoV-2 variant of concern Delta, first detected in India, spread across the world in 2021,
12 and in particular in Europe in late spring – early summer 2021, where it displaced the previously
13 dominant Alpha variant. Delta was shown to be fitter than Alpha,¹⁻³ and may be associated with higher
14 virulence^{4,5} and lesser vaccine effectiveness^{6,7} against symptomatic disease, especially after just one
15 dose.

16 Delta has spread in countries with high vaccination levels, and breakthrough infections have been
17 reported, with Ct values suggesting similar viral loads between vaccinated and unvaccinated infected

18 individuals.⁸⁻¹⁰ A longitudinal study has confirmed similar Ct values between Delta-infected vaccinated
19 and unvaccinated patients in the first week after diagnosis or symptom onset, with later faster decline
20 in vaccinated patients.¹¹ Comparisons of Ct values in infections with Delta compared to infections
21 with previous variants require controlling for infection age when variants has different epidemiological
22 dynamics. This is because viral load depends on infection age, and the distribution of infection ages
23 depends on whether the number of cases is growing or shrinking.¹²⁻¹⁶

24 We studied the determinants of Ct values at the time of test and, for symptomatic individuals, as a
25 function of the time since symptoms, in data from 292284 patients tested by a large private laboratory
26 in the community in France, from 14 June 2021 to 30 July 2021 in three regions (Bretagne, Île-de-
27 France, Provence-Alpes-Côte d'Azur). These data include information on the result of the PCR test,
28 the associated Ct value, the patient's self-reported vaccine status (whether fully vaccinated since at
29 least two weeks, or not), whether the patient has been symptomatic and the time since the onset of
30 symptoms. Positive tests were screened for the L452R mutation, which characterizes the Delta variant
31 (9343 positive tests with mutation information). In the case of multiple tests per individual, we kept
32 the last negative test if there were no positive tests, and the first positive test otherwise.

33 Consistent with the French vaccination campaign, vaccinated individuals are on average older than
34 non-vaccinated patients in our dataset (12 years older). The proportion of vaccinated individuals in
35 the dataset (24%) is lower than in the community (47.5% by 10 July 2021), reflecting the fact that the
36 data are not surveillance-based.

37 Reasons for testing may vary between vaccinated and non-vaccinated individuals. This may especially
38 be the case since France introduced a "sanitary passport," requiring a proof of either full vaccination or
39 a negative test for specific events, which may artificially inflate the proportion of negative tests among
40 non-vaccinated individuals. Conversely, vaccinated individuals may get tested only if they have good
41 reasons to suspect an infection.

42 We compared the cycle threshold (Ct; targeted at gene RdRp) values of the PCR of positive tests
43 depending on vaccine status, the presence of symptoms, and the infecting variant (Delta: presence of
44 the L452R mutation), for the 8437 individuals for which all pieces of information are available. The Ct
45 is the number of PCR cycles needed to detect a target; it is negatively correlated with viral load. We
46 find that the presence of symptoms is associated with significantly lower Ct values (-2.7 Ct [-3, -2.5];
47 adjusted $p < 1e-6$). An infection with the Delta variant is also associated with lower Ct values in these
48 data (-6.7 Ct [-7.1, -6.3]; adjusted $p < 1e-6$); note that age of infection is not controlled for here, but will
49 be later on. Comparing vaccinated and non-vaccinated individuals, we find that vaccinated individuals
50 have significantly higher Ct values for both Delta and non-Delta asymptomatic infections (1.7 [1, 2.3] Ct
51 difference; adjusted $p < 1e-6$), but that the differences are not significant for symptomatic infections (p
52 = 0.8). For non-Delta variants, this result may be due to too small a sample size (only $N = 18$ vaccinated
53 symptomatic individuals infected with non-Delta).

54 Ct values also depend on the age of infection of tested individuals. It is therefore useful to control
55 for age of infection, especially when comparing Ct values of variants with different epidemiological
56 dynamics,^{13,16} as was the case for the Delta (increasing numbers of infections) and Alpha (decreasing
57 numbers of infections) in the early summer in France. To this end, we add time since symptoms onset
58 as a continuous variable in the linear model. We find that the Delta variant has Ct at day of symptoms
59 -3.32 [-4.38, -2.25] lower than non-Delta (Alpha) ($p < 1e-6$, $N = 3439$). The slope of Ct as function of

60 time is 0.6 [0.54, 0.66] per day for Delta and 0.92 [0.73, 1.1] for non-Delta variants ($p < 1e-6$). Vaccine
61 status does not significantly alter the outcomes, whether regarding the Ct at symptom onset ($p = 0.256$)
62 or the slope of Ct as function of time since symptoms ($p = 0.947$) and was therefore not included in the
63 final model.

64 Limitations of our study stem from the way the data were collected: this is a community-based
65 study. Reasons for seeking a PCR test are unknown and may vary among individuals and across time.
66 Symptom and vaccine information are self-reported. Yet our dataset is unique for France, because
67 variant information and vaccine status data have not been linked yet in public datasets, and Ct values
68 are not reported at the national level (only test results are). Our results are in line with a retrospective
69 cohort study which found lower Ct values with Delta and longer duration of infection with low Ct.⁵
70 Regarding vaccine-breakthroughs, our results confirm studies finding similar Ct values among fully
71 vaccinated individuals and those who were not, with the majority of infections being due to Delta.^{8,9}
72 Another limitation of our dataset is the lack of longitudinal data (in Figure 2, each point corresponds
73 to a single patient). A recent study in Singapour found similar Ct values among vaccinated and
74 unvaccinated individuals infected by Delta, at the time of diagnosis or of symptom onset.¹¹ After a week
75 however, Ct values increased faster (i.e. viral load declined faster) among vaccinated individuals than
76 unvaccinated individuals, even after excluding asymptomatic individuals (personal communication).¹¹
77 With transmission occurring early in infection, this delayed differential decrease is expected not to have
78 much of an impact on relative transmissibility.

79 Ct values are linked to viral load, and viral load has been shown to be positively associated with
80 probability of transmission in household contacts – but there is also high inter-individual variation,
81 and transmission from individuals with high Ct values is possible.^{17,18} In spite of these limitations, our
82 confirmatory results indicate that epidemic control may require similar measures for symptomatic
83 PCR-positive vaccinated individuals as non-vaccinated infected individuals.

Acknowledgements

FB was funded by a Momentum grant from the Centre National de la Recherche Scientifique. FD was funded by grant ANR-19-CE45-0009-01 from Agence Nationale de la Recherche.

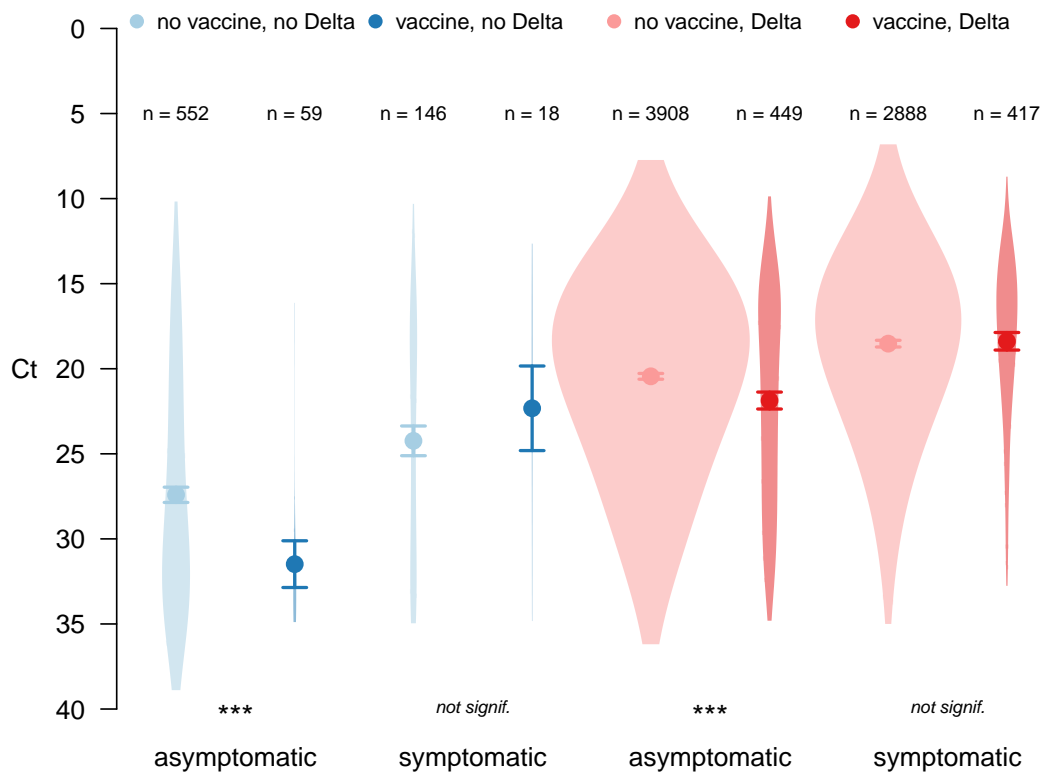
References

1. Campbell F, Archer B, Laurenson-Schafer H, Jinnai Y, Konings F, Batra N, et al. Increased transmissibility and global spread of SARS-CoV-2 variants of concern as at June 2021. *Euro-surveillance* [Internet]. 2021 [cited 2021 Jul 18];26. Available from: <https://www.eurosurveillance.org/content/10.2807/1560-7917.ES.2021.26.24.2100509>
2. Mlcochova P, Kemp S, Dhar MS, Papa G, Meng B, Mishra S, et al. SARS-CoV-2 B.1.617.2 Delta variant emergence and vaccine breakthrough [Internet]. In Review; 2021 Jun [cited 2021 Aug 3]. Available from: <https://www.researchsquare.com/article/rs-637724/v1>
3. Alizon S, Haim-Boukobza S, Foulongne V, Verdurme L, Trombert-Paolantoni S, Lecorche E, et al. Rapid spread of the SARS-CoV-2 Delta variant in some French regions, June 2021. *Eurosurveillance* [Internet]. 2021 [cited 2021 Jul 18];26. Available from: <https://www.eurosurveillance.org/content/10.2807/1560-7917.ES.2021.26.28.2100573>

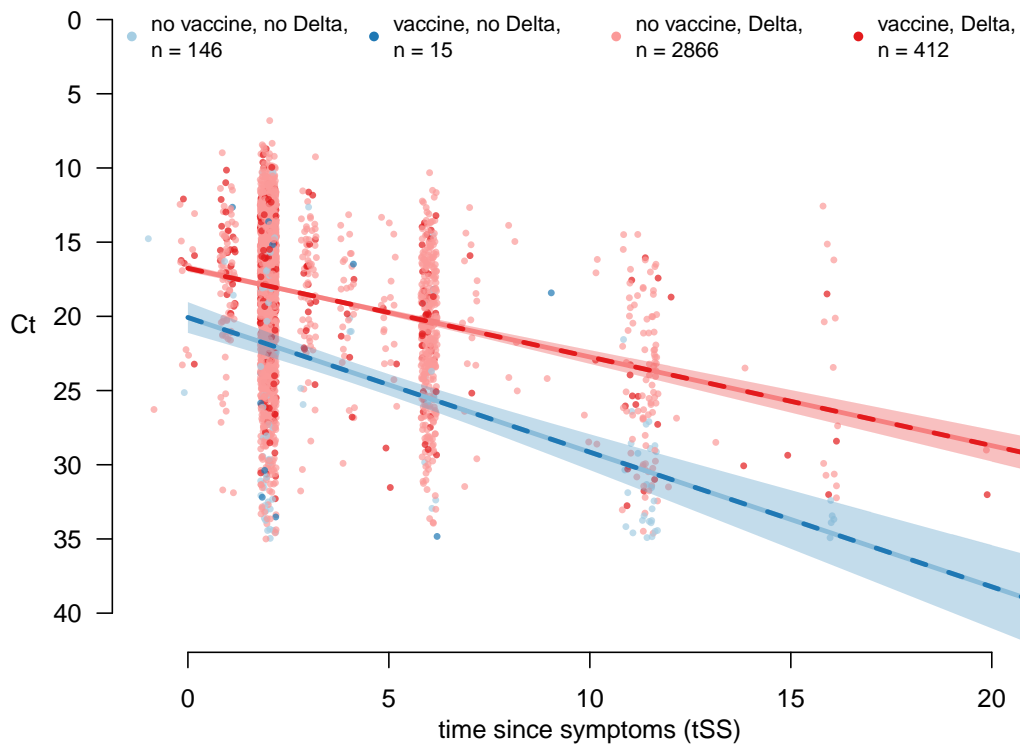
4. Fisman DN, Tuite AR. Progressive Increase in Virulence of Novel SARS-CoV-2 Variants in Ontario, Canada [Internet]. *Infectious Diseases (except HIV/AIDS)*; 2021 Jul [cited 2021 Aug 3]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.07.05.21260050>
5. Ong SWX, Chiew CJ, Ang LW, Mak T-M, Cui L, Toh MPH, et al. Clinical and Virological Features of SARS-CoV-2 Variants of Concern: A Retrospective Cohort Study Comparing B.1.1.7 (Alpha), B.1.315 (Beta), and B.1.617.2 (Delta). *SSRN Electronic Journal* [Internet]. 2021 [cited 2021 Aug 3]; Available from: <https://www.ssrn.com/abstract=3861566>
6. Lopez Bernal J, Andrews N, Gower C, Gallagher E, Simmons R, Thelwall S, et al. Effectiveness of Covid-19 Vaccines against the B.1.617.2 (Delta) Variant. *New England Journal of Medicine* [Internet]. 2021 [cited 2021 Aug 3];NEJMoa2108891. Available from: <http://www.nejm.org/doi/10.1056/NEJMoa2108891>
7. Sheikh A, McMenamin J, Taylor B, Robertson C. SARS-CoV-2 Delta VOC in Scotland: Demographics, risk of hospital admission, and vaccine effectiveness. *The Lancet* [Internet]. 2021 [cited 2021 Jul 18];397:2461–2. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0140673621013581>
8. Brown CM, Vostok J, Johnson H, Burns M, Gharpure R, Sami S, et al. Outbreak of SARS-CoV-2 Infections, Including COVID-19 Vaccine Breakthrough Infections, Associated with Large Public Gatherings — Barnstable County, Massachusetts, July 2021. *MMWR Morbidity and Mortality Weekly Report* [Internet]. 2021 [cited 2021 Aug 2];70. Available from: http://www.cdc.gov/mmwr/volumes/70/wr/mm7031e2.htm?s_cid=mm7031e2_w
9. England PH. SARS-CoV-2 variants of concern and variants under investigation in England. Technical Briefing 16 [Internet]. 2021 Jun. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachme%20nt_data/file/994997/Variants_of_Concern_VOC_Technical_Briefing_16.pdf
10. Elliott P, Haw D, Wang H, Eales O, Walters CE, Ainslie KEC, et al. REACT-1 round 13 final report: Exponential growth, high prevalence of SARS-CoV-2 and vaccine effectiveness associated with Delta variant in England during May to July 2021 [Internet]. 2021 Aug [cited 2021 Aug 9]. Available from: https://spiral.imperial.ac.uk/bitstream/10044/1/90800/2/react1_r13_final_preprint_final.pdf
11. Chia PY, Ong S, Chiew CJ, Ang LW, Chavatte JG, Mak TM, et al. Virological and serological kinetics of SARS-CoV-2 Delta variant vaccine-breakthrough infections: A multi-center cohort study [Internet]. *Infectious Diseases (except HIV/AIDS)*; 2021 Jul [cited 2021 Aug 2]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.07.28.21261295>
12. Alizon S, Selinger C, Sofonea MT, Haim-Boukobza S, Giannoli J-M, Ninove L, et al. Epidemiological and clinical insights from SARS-CoV-2 RT-PCR cycle amplification values [Internet]. *Infectious Diseases (except HIV/AIDS)*; 2021 Mar [cited 2021 Aug 9]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.03.15.21253653>
13. Hay JA, Kennedy-Shaffer L, Kanjilal S, Lennon NJ, Gabriel SB, Lipsitch M, et al. Estimating epidemiologic dynamics from cross-sectional viral load distributions. *Science* [Internet]. 2021 [cited 2021 Jul 18];373:eabh0635. Available from: <https://www.sciencemag.org/lookup/doi/10.1126/science.abh0635>

14. Cosentino G, Bernard M, Ambroise J, Giannoli J-M, Guedj J, Débarre F, et al. SARS-CoV-2 viral dynamics in infections with Alpha and Beta variants of concern in the French community. *Journal of Infection* [Internet]. 2021 [cited 2021 Aug 9];S0163445321003741. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0163445321003741>
15. Althaus CL, Baggio S, Reichmuth ML, Hodcroft EB, Riou J, Neher RA, et al. A tale of two variants: Spread of SARS-CoV-2 variants Alpha in Geneva, Switzerland, and Beta in South Africa [Internet]. *Epidemiology*; 2021 Jun [cited 2021 Jun 18]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.06.10.21258468>
16. Hay JA, Kennedy-Shaffer L, Mina MJ. Viral loads observed under competing strain dynamics [Internet]. *Epidemiology*; 2021 Jul [cited 2021 Aug 2]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.07.27.21261224>
17. Marc A, Kerioui M, Blanquart F, Bertrand J, Mitjà O, Corbacho-Monné M, et al. Quantifying the relationship between SARS-CoV-2 viral load and infectiousness [Internet]. *Epidemiology*; 2021 May [cited 2021 Aug 9]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.05.07.21256341>
18. Lyngse FP, Mølbak K, Træholt Franck K, Nielsen C, Skov RL, Voldstedlund M, et al. Association between SARS-CoV-2 Transmissibility, Viral Load, and Age in Households [Internet]. *Epidemiology*; 2021 Mar [cited 2021 Aug 9]. Available from: <http://medrxiv.org/lookup/doi/10.1101/2021.02.28.21252608>

84 **Figures**



85 Figure 1: Distributions of Ct values, according to vaccine status (light: unvaccinated, dark: vaccinated),
 86 infecting variant (blue: non-Delta, red: Delta) and whether the individual was symptomatic (left:
 87 asymptomatic at least until the test, right: symptomatic). The widths of the violin plots reflect the num-
 88 ber of tests; points and arrows represent predicted values and confidence intervals. “***” means that
 89 the corresponding comparison of unvaccinated and vaccinated individuals is statistically significant
 90 with $p < 0.001$.



91 Figure 2: Regression of Ct value against time since symptoms, for symptomatic individuals, depending
 92 on vaccine status and infecting variant. The lines are the predicted values, the shaded areas the
 93 confidence intervals. The vaccination effect was not significant and therefore removed from the final
 94 model.

95 **Appendix**

96 **Variables**

name	type	description
sympf	factor (0, 1)	Whether the individual is fully vaccinated (1) or not (0)
deltaf	factor (0, 1)	Whether the L452R is detected (1) or not (0)
vacf	factor (0, 1)	Whether the individual is fully vaccinated (1) or not (0)
Ct	numeric	Ct value, RdRp gene
tSS	numeric	Time since symptom onset (days)

97 **Model for Figure 1**

```
mdlAov$call
```

```
98 ## aov(formula = Ct ~ vacf * sympf * deltax, data = tmp)
```

```
summary(mdlAov)
```

```
99 ##                Df Sum Sq Mean Sq  F value    Pr(>F)
100 ## vacf           1    351      351   12.108 0.000505 ***
101 ## sympf          1 15200  15200  524.896 < 2e-16 ***
102 ## deltax         1 32358  32358 1117.379 < 2e-16 ***
103 ## vacf:sympf     1   775    775   26.766 2.35e-07 ***
104 ## vacf:deltax   1   144    144    4.970 0.025819 *
105 ## sympf:deltax  1   359    359   12.412 0.000429 ***
106 ## vacf:sympf:deltax 1   227    227    7.837 0.005130 **
107 ## Residuals    8429 244096      29
108 ## ---
109 ## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
thsd
```

```
110 ## Tukey multiple comparisons of means
111 ## 95% family-wise confidence level
112 ##
113 ## Fit: aov(formula = Ct ~ vacf * sympf * deltax, data = tmp)
114 ##
115 ## $vacf
116 ##      diff      lwr      upr      p adj
117 ## 1-0 0.6470032 0.2825148 1.011492 0.0005046
118 ##
119 ## $sympf
120 ##      diff      lwr      upr p adj
121 ## 1-0 -2.726566 -2.960009 -2.493124 0
122 ##
```

```

123 ## $deltaf
124 ##          diff          lwr          upr p adj
125 ## 1:0 -6.72394 -7.121566 -6.326314 0
126 ##
127 ## $\`vacf:sympf`
128 ##          diff          lwr          upr          p adj
129 ## 1:0-0:0 1.6816459 1.0341760 2.3291159 0.0000000
130 ## 0:1-0:0 -2.5080529 -2.8335307 -2.1825750 0.0000000
131 ## 1:1-0:0 -2.7595748 -3.4541112 -2.0650384 0.0000000
132 ## 0:1-1:0 -4.1896988 -4.8526381 -3.5267595 0.0000000
133 ## 1:1-1:0 -4.4412207 -5.3445110 -3.5379303 0.0000000
134 ## 1:1-0:1 -0.2515219 -0.9605014 0.4574576 0.7986775
135 ##
136 ## $\`vacf:deltaf`
137 ##          diff          lwr          upr          p adj
138 ## 1:0-0:0 2.0758433 0.4153934 3.736293 0.0072293
139 ## 0:1-0:0 -6.5769166 -7.1265213 -6.027312 0.0000000
140 ## 1:1-0:0 -5.9746925 -6.6780558 -5.271329 0.0000000
141 ## 0:1-1:0 -8.6527600 -10.2374675 -7.068052 0.0000000
142 ## 1:1-1:0 -8.0505358 -9.6949058 -6.406166 0.0000000
143 ## 1:1-0:1 0.6022242 0.1033012 1.101147 0.0104180
144 ##
145 ## $\`sympf:deltaf`
146 ##          diff          lwr          upr p adj
147 ## 1:0-0:0 -3.824406 -5.040470 -2.608343 0
148 ## 0:1-0:0 -7.225312 -7.822622 -6.628002 0
149 ## 1:1-0:0 -9.324285 -9.933266 -8.715303 0
150 ## 0:1-1:0 -3.400906 -4.500778 -2.301033 0
151 ## 1:1-1:0 -5.499879 -6.606133 -4.393624 0
152 ## 1:1-0:1 -2.098973 -2.417982 -1.779963 0
153 ##
154 ## $\`vacf:sympf:deltaf`
155 ##          diff          lwr          upr          p adj
156 ## 1:0:0-0:0:0 4.0748024 1.8402263 6.30937863 0.0000009
157 ## 0:1:0-0:0:0 -3.1720965 -4.6903764 -1.65381653 0.0000000
158 ## 1:1:0-0:0:0 -5.0857054 -8.9932302 -1.17818060 0.0020482
159 ## 0:0:1-0:0:0 -6.9645855 -7.7063452 -6.22282583 0.0000000
160 ## 1:0:1-0:0:0 -5.5406910 -6.5774897 -4.50389237 0.0000000
161 ## 0:1:1-0:0:0 -8.8873726 -9.6453033 -8.12944188 0.0000000
162 ## 1:1:1-0:0:0 -9.0238193 -10.0823280 -7.96531060 0.0000000
163 ## 0:1:0-1:0:0 -7.2468989 -9.7636751 -4.73012268 0.0000000
164 ## 1:1:0-1:0:0 -9.1605078 -13.5534270 -4.76758868 0.0000000
165 ## 0:0:1-1:0:0 -11.0393880 -13.1792936 -8.89948235 0.0000000
166 ## 1:0:1-1:0:0 -9.6154935 -11.8746836 -7.35630334 0.0000000

```

167 ## 0:1:1-1:0:0 -12.9621750 -15.1077397 -10.81661041 0.0000000
168 ## 1:1:1-1:0:0 -13.0986217 -15.3678571 -10.82938634 0.0000000
169 ## 1:1:0-0:1:0 -1.9136089 -5.9890944 2.16187654 0.8466421
170 ## 0:0:1-0:1:0 -3.7924891 -5.1676397 -2.41733844 0.0000000
171 ## 1:0:1-0:1:0 -2.3685946 -3.9228736 -0.81431555 0.0001056
172 ## 0:1:1-0:1:0 -5.7152761 -7.0992165 -4.33133582 0.0000000
173 ## 1:1:1-0:1:0 -5.8517228 -7.4205671 -4.28287852 0.0000000
174 ## 0:0:1-1:1:0 -1.8788802 -5.7330487 1.97528842 0.8194703
175 ## 1:0:1-1:1:0 -0.4549857 -4.3766383 3.46666698 0.9999686
176 ## 0:1:1-1:1:0 -3.8016672 -7.6589806 0.05564621 0.0567588
177 ## 1:1:1-1:1:0 -3.9381139 -7.8655620 -0.01066581 0.0488069
178 ## 1:0:1-0:0:1 1.4238945 0.6109881 2.23680092 0.0000031
179 ## 0:1:1-0:0:1 -1.9227871 -2.3231923 -1.52238184 0.0000000
180 ## 1:1:1-0:0:1 -2.0592338 -2.8996539 -1.21881362 0.0000000
181 ## 0:1:1-1:0:1 -3.3466816 -4.1743701 -2.51899298 0.0000000
182 ## 1:1:1-1:0:1 -3.4831282 -4.5926552 -2.37360130 0.0000000
183 ## 1:1:1-0:1:1 -0.1364467 -0.9911733 0.71827990 0.9997296

184 **Model for Figure 2**

185 **Full model**

```
mdl$call
```

```
186 ## lm(formula = Ct ~ vacf * deltax * tSS, data = dat.nodupl)
```

```
car::Anova(mdl)
```

```
187 ## Anova Table (Type II tests)
```

```
188 ##
```

```
189 ## Response: Ct
```

```
190 ##           Sum Sq  Df F value    Pr(>F)
191 ## vacf           27   1  1.2884  0.256427
192 ## deltax        3192   1 152.3081 < 2.2e-16 ***
193 ## tSS           9487   1 452.6392 < 2.2e-16 ***
194 ## vacf:deltax     5   1  0.2289  0.632364
195 ## vacf:tSS        0   1  0.0044  0.947141
196 ## deltax:tSS     211   1  10.0434 0.001542 **
197 ## vacf:deltax:tSS 44   1  2.1114 0.146299
198 ## Residuals    71911 3431
```

```
199 ## ---
```

```
200 ## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

201 **Reduced model with significant effect only (used for the Figure)**

```
mdl1$call
```

```
202 ## lm(formula = Ct ~ deltax + tSS + deltax * tSS, data = dat.nodupl)
```

```
car::Anova(mdl1)
```

```
203 ## Anova Table (Type II tests)
```

```
204 ##
```

```
205 ## Response: Ct
```

```
206 ##           Sum Sq  Df F value    Pr(>F)
207 ## deltax        3231   1 154.156 < 2.2e-16 ***
208 ## tSS           9512   1 453.905 < 2.2e-16 ***
209 ## deltax:tSS     228   1  10.872 0.0009863 ***
210 ## Residuals    71987 3435
```

```
211 ## ---
```

```
212 ## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```