



VIEWPOINT

Aggregates versus pores – is the soil science community torn apart? A survey

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Abstract

Whether soil structure should be viewed mostly as a system of pores or a set of aggregates is a question soil scientists keep debating in the literature, but it is unclear whether the wider soil science community is also divided. In a quick survey among mainly German soil scientists of all career levels and sub-disciplines, most participants agreed that both pores and aggregates are important to describe soil structure. The debate can nevertheless be fruitful if it is led more efficiently, avoiding generalisations, misunderstandings and potential emotional barriers.

KEYWORDS

aggregate perspective, debate, holistic, pore perspective, soil functions, soil structure

1 | INTRODUCTION

Soil structure has been defined as ‘the spatial arrangement of primary particles and pores’ (Koestel et al., 2021), and many earlier definitions are similar to this one (e.g., Dexter, 1988; Lal, 1991). Despite this apparent agreement, there is a debate going on between soil scientists taking different perspectives on soil structure. The two main viewpoints have been called ‘aggregate perspective’ and ‘pore perspective’. Their debate mostly circulates around the usefulness of the concept of aggregates in different contexts.

Proponents of the aggregate perspective view the structure of most soils as consisting of aggregates, that is, clusters of particles cohering more strongly with each other than with neighbouring particles (Yudina & Kuzyakov, 2019). This usually includes a distinction between regions at the surface and the inside of aggregates and between inter- and intra-aggregate pores (Kladivko, 2017). A further feature of this perspective is that aggregation is thought to have distinct hierarchical levels with smaller aggregates being more stable and being contained within larger ones (Tisdall & Oades, 1982). The organisation of soil into aggregates is thought to drive important soil functions like carbon turnover according to this perspective (see, e.g., Meyer et al., 2024).

Studies using this approach in most cases include the separation of soil clods into smaller pieces either by mechanical force or by use of water.

Proponents of the pore perspective are mostly sceptical of the fragmentation of soils into aggregates, both in terms of actual methods and in terms of concepts. They consider the aggregate approach to not be useful for many soils and in most use cases, for example when soil functions like fluxes of matter or energy are quantified, particularly if these are upscaled to whole soil profiles or landscapes (Kravchenko et al., 2019; Vogel et al., 2022). Instead, they state that the pore system as a whole drives most soil functions. Therefore, they emphasise that soils should be studied using larger samples than the typical size of studied aggregates (up to ca. 2 cm) to include processes occurring at larger scales and to maintain more spatial information, like, for example, the orientation of the sample in the soil. The aggregate concept is not needed for the explanation of soil functions according to this perspective.

Occasional criticism of studying fragmented soil dates back as far as 1938, when Kubiěna compared a ‘crushed or pulverised soil’ to a ‘demolished building’ (Kubiěna, 1938). Many years later, this criticism was refined (Letey, 1991; Young et al., 2001), and recently, the debate has intensified with numerous papers and letters to the editor dealing

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with this issue (Garland et al., 2024; Kravchenko et al., 2019; Rabot et al., 2018; Vogel et al., 2022; Yudina & Kuzyakov, 2019; Yudina & Kuzyakov, 2023).

When I came across this debate during my Master's thesis on the stability and structure of aggregates from a field experiment, it appeared to me that the soil science community was divided. Moreover, some authors described this debate between the two 'fundamentally different' (Vogel et al., 2022) perspectives as 'controversial' (Yudina & Kuzyakov, 2019), leading to 'a rift in the soil science community' (Garland et al., 2024). However, the impression of two distinct camps could be misleading because only scientists with strong opinions about that matter are likely to make the effort to write a paper about it. Therefore, it is unclear how the wider soil science community relates to that issue, which leads to two questions: (1) *How is the (intensity of) agreement with aggregate and pore perspective distributed among soil scientists?* In addition, regarding the supposed fundamental difference between them, (2) *how many soil scientists see the two main perspectives as compatible or mutually exclusive?*

Despite its long history, the problem has not been solved yet. In fact, involved scientists do not even always agree on what the core of the conflict is (Kravchenko, 2023) or whether there should be any conflict at all (Garland et al., 2024). This raises the question of whether there are non-argumentative factors that affect the communication on this matter.

Proponents of the aggregate perspective have been criticised for sticking to the aggregate concept simply because they were used to it (Baveye, 2023). Belief perseverance in spite of contradicting experimental data can in fact occur in natural scientists (Nissani & Hoefler-Nissani, 1992). Notably, this applies to all soil scientists involved, irrespective of their opinion on the matter. Moreover, scientists who have used either approach in their work can feel they wasted their time if they abandon the underlying concept (sunk cost effect; Arkes & Blumer, 1985). The longer they have worked with it, the more is at stake for them. Alternatively, scientists may have found increasing evidence for the usefulness of their concept during their career. Both could make scientists develop stronger opinions about that matter as they reach later career stages. Disentangling the causes would be interesting, but before that, it is necessary to find out: (3) *Does the strength of opinion increase with increasing career stage?*

Referring to the three questions named above, this study aims to test the following hypotheses:

1. The positions in the soil science community are not as polarised as the literature suggests.
2. Most soil scientists judge the two perspectives to be compatible.
3. The strength of opinions increases with increasing career stage.

The approach taken here was to have a look at this debate from a social sciences' perspective, doing a survey among soil scientists. The aim was to get a clearer picture of social aspects of the status quo of the debate.

2 | METHODS

The survey was designed to (1) include as many soil scientists as possible and (2) introduce as little bias as possible. Aspects like accessibility, self-selection, prevention of questionnaire abortion, biased answer behaviour and suggestive questions were considered.

Accessibility was supported by conducting the survey online, published via the mailing list of the German Soil Science Society (Deutsche Bodenkundliche Gesellschaft [DBG], on 17 February 2023) and posted on Twitter (today 'X', on 6 April 2023). It was formulated in English to reach an international audience. Participation was anonymous by default.

People interested in a topic are more likely to participate in a related survey, which is a case of self-selection bias (Whitehead, 1991). Overcoming this bias was critical regarding the first hypothesis. As an additional motivation, participants were offered to take part in a lottery with eight prizes having a soil-related printing. The (optional) participation in the lottery required entering their email address, which compromised participants' anonymity, and they were made aware of that.

To avoid frustration and thus abortion of filling out the online form, the questionnaire was kept short (18 questions including subquestions, ca. 5–10 min), and only little personal information was asked for (Table S1). Most of the questions were closed type, that is, offering a limited set of answers to choose from, and only 10 questions were mandatory. When asking for (dis)agreement with different statements, the scale from 'strong disagreement' to 'strong agreement' had an even number of answer options to avoid the effect that (especially weakly motivated) participants tend to choose the option in the middle (Bishop, 1987; Masuda et al., 2017).

Definitions of the 'aggregate perspective' and 'pore perspective' are contested themselves. An inadequate definition of a perspective might make it seem less appropriate. Therefore, to not introduce any bias, no definitions were given, and participants were asked to use their own understanding of the terms.

The questionnaire consisted of five question blocks (Table S1). The first two blocks covered details regarding the participants' scientific career and working place, and their self-estimated level of expertise on the matter. Then followed an array of statements where participants could rate their (dis)agreement. In the fourth block, participants were explicitly asked for their preference for the aggregate or the pore perspective, with the additional options 'equally agree with both', 'no opinion' and 'do not have enough knowledge to judge'. If one of the two perspectives was favoured, an additional question opened asking them for the strength of their opinion. Additionally, participants were asked to rate the relevance of the debate to their own research and to soil science in general. The last block allowed to elaborate on any thoughts on that topic in a free-text field and to give feedback on the questionnaire.

Data analysis and figure plotting were done with R (Pedersen & Crameri, 2023; R Core Team, 2023; Wickham, 2016; Wickham et al., 2022).

3 | RESULTS

3.1 | Characteristics of the participants

In total, 350 people started the survey (via DBG mailing list, called 'DBG' from here on: 228; via Twitter: 122) and 280 completed it (DBG: 189, Twitter: 91). Of these, 251 stated that they were academic researchers (DBG: 171, Twitter: 80). As the target group was academic soil scientists, only these 251 complete questionnaires were analysed. The answers from both sub-surveys were very similar, so pooled results are presented here.

More than half of the participants (139) had their workplace in Germany, followed by the USA (29), Switzerland (21) and 1–6 scientists each from 30 countries on all continents (Table S2). All career stages were represented, namely, PhD students (69), PostDocs (76), (assistant/associate/full) professors (56), retired (10) and others (40). In a multiple-choice question about the research focus area, the three main soil science sub-disciplines were almost equally frequent (soil [micro] biology/ecology: 95, soil chemistry: 110, soil physics: 93), with markedly fewer scientists working in hydrology (28), mineralogy (16) and other sub-disciplines (64). The self-estimated expertise on the debate was moderate to high with most people rating their expertise as 'rather low' (54), 'rather high' (87) or 'high' (66). Only few people judged their expertise as 'very high' (22), 'low' (14), 'very low' (7) or gave no answer (1).

3.2 | Polarisation (hypothesis 1)

The answers on a scale from 'strongly disagree' to 'strongly agree' (questions C1a–f) all had unimodal distributions (Figure 1). The two opposing phrases regarding the (non-)existence of aggregates got very different reactions (Figure 1a,b). Most participants strongly (136), moderately (66) or rather agreed (27) with the statement that aggregates exist and have characteristics that are typical of different soils (a phrase cited from Kravchenko et al., 2019). In contrast, the phrase stating that 'aggregates are merely artifacts and do not exist in soils in their natural state', rephrased from a – supposedly rhetorical – question in Yudina and Kuzyakov (2019), mostly got negative reactions from 'strongly disagree' (128) over 'moderately disagree' (45) to 'rather disagree' (43).

The agreement with the phrase 'In order to understand soils, the concept of aggregates is important' was high with 142 participants agreeing strongly (Figure 1c). The same statement referring to pore systems instead of aggregates got even higher agreement with 187 participants agreeing strongly (Figure 1d).

When directly asked to position themselves regarding the pore and aggregate perspective, a simple majority (124 of 251; 49%) equally agreed with both perspectives (Figure 2a). Eighty-nine participants (35%) agreed more with either perspective, and 40 participants (16%) strongly agreed with one of them.

3.3 | Complementary or exclusive? (hypothesis 2)

Two statements were presented to participants to ask them whether they deemed the aggregate and the pore perspective to be complementary or conflicting (Figure 1e,f). The phrase stating that they are conflicting got mostly strong agreement (136), followed by moderate agreement (66). The other phrase saying that the two perspectives were 'two sides of one coin' got weaker agreement with 99 participants agreeing strongly and 48 moderately. Thus, although these phrases were meant to express opposite views, both were mainly agreed with.

3.4 | Correlation of polarisation with career stage (hypothesis 3)

From the visual impression in Figure 2b, all career stages contribute equally to the different answers regarding the question of which perspective they prefer. The statistical tests support this impression. Spearman's rank correlations between career stage and the strength of opinions regarding the different statements (questions C1a–f; see Table S1) and regarding the explicit preference for one perspective (question D2) were all positive but generally low (Spearman's rho 0.02–0.17; Table S3). Only one of the correlation coefficients was significant at an alpha level of 0.05 (one-sided test). Note that the true *p*-value was uncertain because the data set contained many ties (participants sharing the same rank).

Results were similar but more variable when correlating self-estimated expertise with strength of opinion. Spearman's rho in these cases ranged from 0.07 to 0.34, and four of the correlation coefficients were significantly positive at an alpha level of 0.05 (one-sided test; Table S4). Again, due to many ties in the data set, the true *p*-value could not be calculated exactly.

4 | DISCUSSIONS

4.1 | Representativeness

As presented in Section 4.1, 139 of 251 participants (55%) worked in Germany. I, therefore, doubt that the results are representative of the world-wide soil science community. The German soil science community, however, is likely to be represented well because of the balanced mixture of career stages and sub-disciplines.

4.2 | Low polarisation and no correlation with career stage

Participants by majority strongly agreed with the importance of the aggregate concept and, consistently, disagreed with the statement that they do not exist in natural soils. At the same time, they strongly agreed

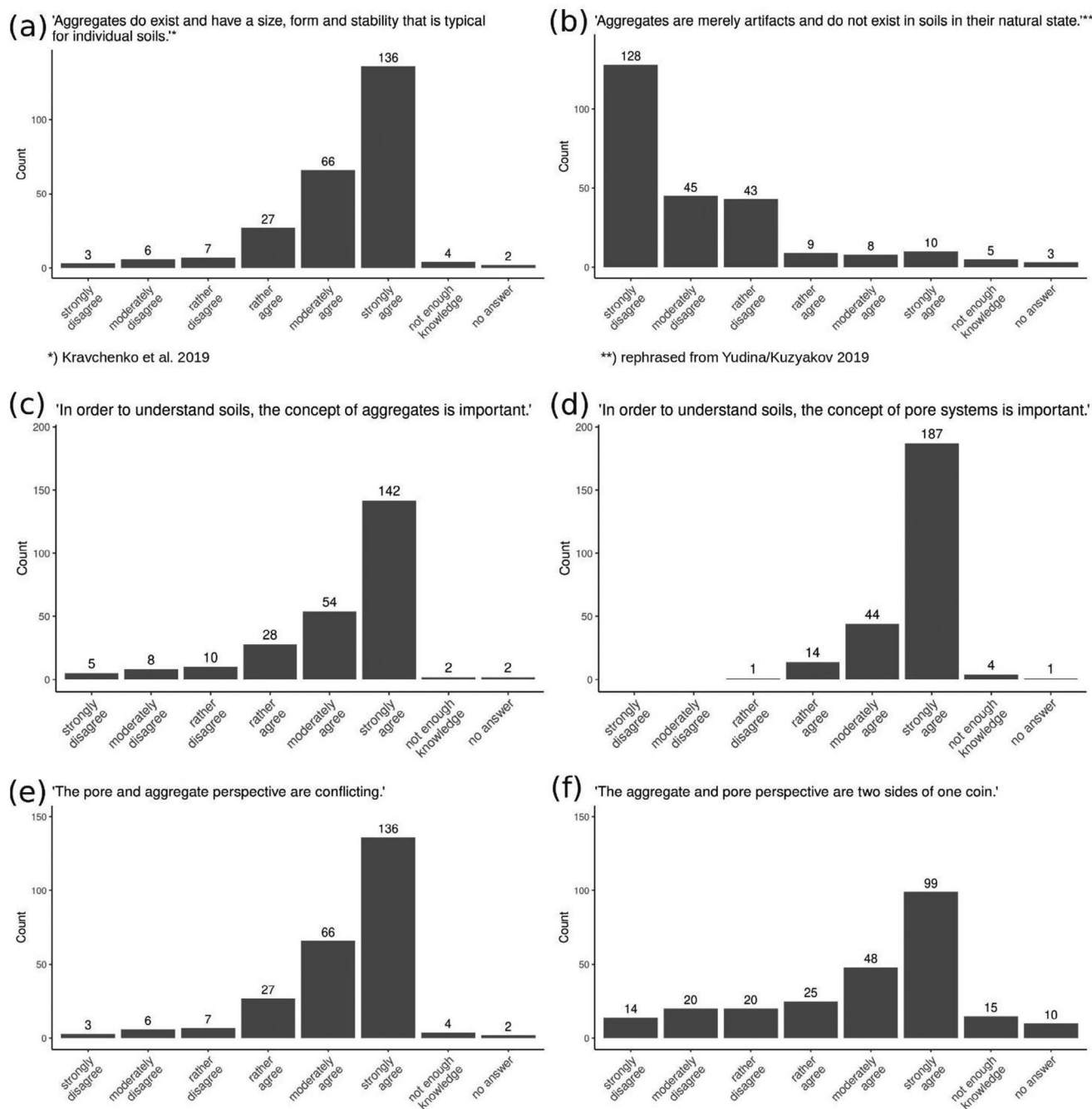


FIGURE 1 Survey results: reactions to the statements given in the title of each sub-figure (a–f) (absolute numbers, both sub-surveys combined, only academic researchers and complete questionnaires).

with the importance of the pore concept to understanding soils. This is also reflected by 124 participants (49%) stating that they equally agree with both perspectives. Among the 89 participants (35%) who favoured one of the perspectives, a large group (40 participants) had a strong opinion about that matter, which may explain the controversial debate. However, these 40 scientists only represented a minority (16%) of all participants.

None of the statements (C1a–f) had a bimodal distribution of answers, which could have hinted at two groups with opposing views. These results are consistent with the assumption that the (German)

soil science community as a whole is not as polarised regarding perspectives on soil structure as a reading of the literature might suggest. Admittedly, it is difficult to compare these data to the polarisation of views represented in the literature because the latter is hard to quantify. Nevertheless, a majority of participants equally agreeing with both perspectives is not compatible with a view of 'fundamentally different' (Vogel et al., 2022) perspectives, so I consider my first hypothesis confirmed. Note that this is not a statement about the validity of either viewpoint but only about their representation within the scientific community.

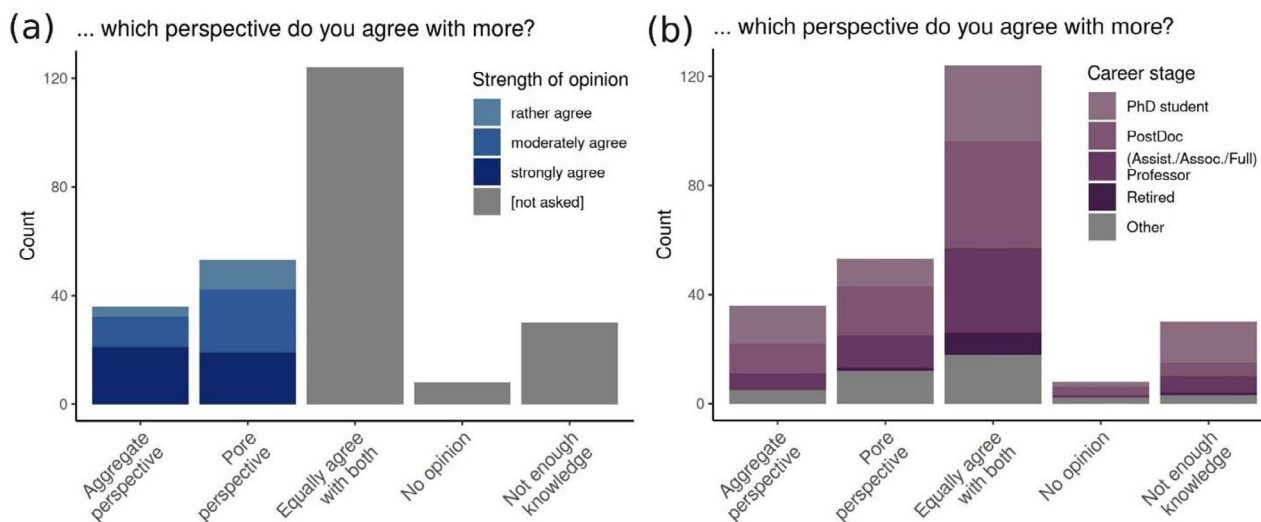


FIGURE 2 Reactions when explicitly asked for a preference for aggregate or pore perspective (absolute numbers, both participant pools ('DBG' and 'Twitter') combined, only academic researchers and complete questionnaires). (a) Columns sub-divided by strength of opinion. Only those who agreed with one of the perspectives were asked for that. (b) The same graph as (a) with columns sub-divided by career stage of the participants.

Given such a low degree of polarisation, it is not very surprising to not find any strong correlations of strength of opinion with career stage. Thus, the second hypothesis could not be confirmed. Correlations of self-estimated expertise with strength of opinion tended to be stronger but were not consistently significant ($p < 0.05$), either. Thus, in this group, no hint to irrational belief perseverance could be found. It may nevertheless be effective in individuals or groups in the soil science community, but in this study, I found no sign of it.

4.3 | Complementary or exclusive?

The opposing statements that the two main perspectives in the debate are either 'conflicting' or 'two sides of one coin' both got much agreement. This contradiction may be explained with misunderstandings. First, 'two sides of one coin' might have been misunderstood as 'opposing sides' instead of 'two parts of the same thing', especially in countries where there is no equivalent to this English saying. Second, 'The pore and aggregate perspective are conflicting' may have been misunderstood as 'There is a conflict between scientists preferring either the pore or the aggregate perspective'. Nevertheless, it is reasonable to assume that the vast majority of scientists who deem both perspectives to be important to understand soils (questions C1a and f) and who do not prefer one perspective over the other (question D1) will consider them complementary.

5 | CONCLUSIONS AND OUTLOOK

The survey presented here is a first peek into social and psychological aspects and the status quo of the debate. It showed that perspectives of soil scientists are more moderate than what the literature makes it seem. I want to stress that this survey was not meant to decide

democratically whether the different positions really are compatible or which one is the better one. Instead, these results may serve as a starting point for further investigations and debates.

Further investigations, preferably done by researchers in psychology, may be helpful to identify potential barriers to effective communication. If non-argumentative factors such as misunderstandings or irrational belief perseverance were found to hinder the debate, this could inform the design of communication techniques that alleviate these barriers.

Misunderstandings seem to affect the debate because occasionally, scientists wrote that their point of view had been misrepresented by others (e.g. see comments in the open review of Garland et al., 2024). To improve the efficiency of the debate, communication techniques that help avoid misunderstandings should be employed (e.g. clear definition of terms, being specific and careful with generalisations). Moreover, a very clear intention to first understand a scientist's view before reacting to it could be beneficial. Moreover, debate participants should strive to create a constructive atmosphere to not provoke unnecessary emotional resistance. Irony and sarcasm should be used sparingly when confronting scientists with criticism of their approach.

Many survey participants mentioned in the free-text field that they had not been aware of the debate, and many also had doubts about its relevance. As part of the debate, it should apparently be made clearer which consequences arise from following one or the other perspective, like the context in which certain sampling and sample preparation procedures (especially sieving) or experimental setups, for example, with repacked soil aggregates, are used or avoided and the conclusions that are drawn from measurements done on small soil samples.

Moreover, it needs to be settled whether the two perspectives are in conflict with each other or not. Possibly, the pore-aggregate duality is in soil science what the wave-particle duality is in physics: The models complement each other in explaining the object of research. However, the whole point of the pore perspective, as it seems to me,

is a criticism of the aggregate model, which, in its most pointed form, questions whether we need aggregates at all to explain soil functions (Baveye, 2023). If proponents of the 'aggregate perspective' could not come up with anything convincing, it would get hard to argue why funds should be allocated to research relying on that concept. On the other hand, convincing use cases of this concept, for example, for predicting nutrient cycling or biological activity, would in turn consolidate arguments in favour of 'aggregate-based' research and mark the realm where this concept has its strengths. The aggregate concept may also be modified and refined during this evaluation process, so proponents of the 'aggregate perspective' should see this criticism as a chance for progress.

I, therefore, see value in the debate, even though it is led by a minority in soil science. In my view, it is worth investing the time to understand, structure and continue this debate. Researchers interested in that are warmly welcome to reach out to me.

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DATA AVAILABILITY STATEMENT

The data that supports the finding of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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