CORRESPONDENCE

What We Can and Cannot Conclude About the Relationship Between Steep Temporal Reward Discounting and Hyperactivity-Impulsivity Symptoms in Attention-Deficit/Hyperactivity Disorder

To the Editor:

Paloyelis et al. (1) raise two concerns about the statistical methods used in the original article by Scheres et al. (2); first, they indicate that analysis of covariance (ANCOVA) is inappropriate when groups differ on the covariate; and second, they suggest that the results from the regression analysis might be an artifact resulting from pooling heterogeneous populations. To remedy the latter, they recommend including group membership in the regression analysis. We point out that the resulting analysis—a multiple regression analysis (MRA) with group membership included—is identical to ANCOVA (3–7). Hence, the very mistake they flag in the first analysis is their proposed remedy in the second analysis.

Originally, ANCOVA was developed as a statistical tool for increasing the power to detect the effect of an experimental manipulation through reducing the unexplained variance in the dependent variable (DV). This is illustrated on the left in Figure 1.

When groups differ on the covariate, however, the two IVs will, in part, account for the same variance in the DV, and hence the (statistical) effect of the grouping variable will depend on whether or not the covariate is included in the analysis. This is illustrated on the right in Figure 1: when the covariate is not included, group membership explains a and d, but when the covariate is included, only the direct effect a is uniquely accounted for by group membership. The overlap between the grouping variable and the covariate (i.e., d and e) may be due to a causal effect of the grouping variable on the covariate or vice versa, or both IVs may be influenced by an omitted variable. Statistically, it is impossible to distinguish between these scenarios (5). Hence, if the groups differ on the covariate, including both the covariate and the grouping variable implies that only the direct effects of these IVs are estimated (i.e., a and b).

This is the reason some argue ANCOVA is inappropriate if groups differ on the covariate; it may partial out part of the total effect of the grouping variable (i.e., the indirect effect of group on the DV through the covariate). However, there is nothing inherently wrong with performing an ANCOVA (it is just an MRA with a grouping variable and a continuous variable on which the groups differ), as long as one realizes that causal statements regarding the effect of group membership on the DV should be made with caution. (Note that causal statements based on existing—rather than randomly assigned—groups should always be made with caution.)

To show that the ANCOVA and MRA are, in fact, the same analysis, Table 1 contains the results when both the grouping variable (ADHD subtypes) and hyperactivity-impulsivity are included. It shows that 1) the overall F test is the same for the two analyses; 2) the p values for the separate effects of the IVs/predictors are the same across the two analyses; and 3) while the overall model is significant, neither of the IVs/predictors reaches significance.

The latter is the result of multicollinearity, that is, a large overlap between the IVs. In this case, the correlation between the continuous predictor and the grouping variable is .790, which is not surprising given that the ADHD subtypes were based on the hyperactivity/impulsivity scores. A well-known and unfavorable effect of multicollinearity is that the parameter estimates become extremely unstable, which, in turn, results in a failure to reach significance when considered simultaneously, even though the IVs/predictors are significant when considered by themselves (see original article [2]). A typical remedy in such situations is to include only one of the two IVs/predictors (5–7).

In the current context, this implies we could decide to keep the grouping variable and perform an analysis of variance (i.e., a regression analysis with a dummy variable for group membership as predictor), or alternatively, we could keep the continuous predictor and perform a regression analysis. If we choose the continuous predictor, we need to be aware that the found association between the predictor and DV may be (partly) attributed to mean differences between groups on the IV/predictor and the DV, as suggested by Paloyelis et al. (1). However, the opposite is also true: if we choose the grouping variable, group differences on the DV may be an artifact of a linear relation between the continuous predictor and the DV.

Given that the large overlap between the grouping variable and hyperactivity-impulsivity prompts us to choose between them, an important question to consider is “does our sample consist of two separate populations, or are the ADHD subtypes a convenient

Table 1. Results from ANCOVA and MRA with Area Under the Discounting Curve for Condition 3 as the Dependent Variable

<table>
<thead>
<tr>
<th>Model</th>
<th>Group</th>
<th>Hyperactivity-Impulsivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANCOVA</td>
<td>F(2,39) = 3.96</td>
<td>p = .027</td>
</tr>
<tr>
<td>MRA</td>
<td>F(2,39) = 3.96</td>
<td>b2 = -.10</td>
</tr>
<tr>
<td></td>
<td>R² = 1.7</td>
<td>(SE = .07)</td>
</tr>
<tr>
<td></td>
<td>p = .027</td>
<td>p = .204</td>
</tr>
</tbody>
</table>

Results showing the equivalence between analysis of covariance and multiple regression analysis. Group membership and hyperactivity-impulsivity are included as independent variables in the analysis of covariance; the regression equation can be expressed as y = b0 + b1D + b2x + b3G, where D is a dummy variable to identify participants in the ADHD-Combined Type group (i.e., they have a score of 1 on this variable, while the others score 0 on this variable), and H is the score on Hyperactivity-Impulsivity. ANCOVA, analysis of covariance; MRA, multiple regression analysis.

Venn diagrams when groups do not differ on the covariate (left) and when groups differ on the covariate (right).

Figure 1. Venn diagrams when groups do not differ on the covariate (left) and when groups differ on the covariate (right).
fiction resulting from an arbitrary segmentation of a dimension? (8,9). Although there are statistical procedures to investigate this (8), the current analyses do not provide information on which to base such a decision. Therefore, we may use prior research on the validity of subtypes (e.g., [10]), as well as theoretical and methodological considerations (8,11) to inform our decision. In addition, it is important that if we choose the continuous approach (i.e., if we consider ADHD to be a single population), the sample should be representative of this population, as was the case in the Scheres et al. study (2).

Taking into account these considerations, we can conclude that whether we choose the categorical or the continuous IV/predictor, a significant and substantial proportion of the variance in the DV temporal reward discounting can be explained by symptoms of hyperactivity and impulsivity. That is, group membership explained 16%, while hyperactivity-impulsivity explained 13%; note that this difference is not statistically significant. These percentages did not significantly increase when we included inattention and/or age in the model. Hence, based on the original analysis of variance (2), the lack of relation between inattention and the DV, and the additional analyses described here, we conclude the following: within this heterogeneous sample of children and adolescents with ADHD, the relation between temporal reward discounting and hyperactivity/impulsivity symptoms, whether defined continuously or categorically, could not be attributed to inattention or age.

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