Circulating Testosterone Levels and Aggression in Adolescent Males: A Causal Analysis

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Empirical analyses conducted within a causal–analytic framework (path analysis) on a sample of normal adolescent human males suggested that circulating levels of testosterone in the blood had a direct causal influence on provoked aggressive behavior (self-reports): A high level of testosterone led to an increased readiness to respond vigorously and assertively to provocations and threats. Testosterone also had an indirect and weaker affect on another aggression dimension: High levels of testosterone made the boys more impatient and irritable, which in turn increased their propensity to engage in aggressive-destructive behavior. Two somewhat parallel dimensions of behavior, intermale and irritable aggression, have been identified in animal research to be under testosterone control.

There is little doubt that circulating levels of testosterone during the fetal stage have profound organizational effects on the brain of human and nonhuman primate males. These effects include an increased readiness to engage in aggressive behavior (e.g., 1–3).

There is more uncertainty as to whether circulating levels of testosterone in the blood at or after puberty are related in a systematic way to aggressive behavior. Studies on human males have given somewhat conflicting results (see, e.g., 1, 4, for references). However, when combined with findings from animal research (2, 3), the studies with human males suggest that there may be a positive relationship between plasma testosterone levels in adolescence and adulthood and one or more aspects of aggressive behavior. For animals, the findings also indicate that testosterone level at puberty may have a causal influence on some forms of aggressive behavior. This, of course, does not preclude the possibility of an individual's level of testosterone being at the same time affected by environmental and experiential factors (including the individual's own behavior).

In a recent study of adolescent boys (4), we found a clear positive relationship between circulating plasma testosterone levels and certain forms of aggressive behavior. However, establishing such a relationship is not a sufficient condition for linking testosterone causally to aggressive behavior. Obviously, the testosterone-behavior correlation may be a function of some common prior variables that have not been measured.

To make a more convincing test of the hypothesis that testosterone influences one or more forms of aggressive behavior, the following kinds of data are desirable: a) measures of the relevant aggres-

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sion dimensions before the production of testosterone (in sizable quantities) is initiated, as well as after it has continued for some time (such measures were available in the present project); and b) measures of other, causally prior variables that may affect the subject's level of testosterone as well as his aggression dimensions. In the present study, we had access to several data of this kind, covering temperamental characteristics of the subjects and parental child-rearing dimensions during childhood. In an earlier study of the same boys (5), these variables have been shown to be of considerable importance for the development of aggressive reaction patterns.

If there are indications that testosterone has an influence on the aggressive behavior dimensions even after the variables listed under (a) and (b) have been controlled for, the hypothesis of a causal, nonspurious relationship will be considerably strengthened. Further, if a causal interpretation is plausible, it is of great interest to examine the mechanisms involved in the relationship. Does testosterone have a direct effect on the relevant aggression dimension, or is the effect indirect, mediated by one or more intervening variables?

We address these two basic issues in the present article. They can be succinctly formulated as follows: a) Are there indications of a causal effect of circulating plasma testosterone on one or more aggressive behavior dimensions in male adolescents when antecedent, potentially causal variables are controlled for? b) Provided such effects are found, what is the nature of these effects? So far as we know, such comprehensive analyses of testosterone–aggression relationships in humans have not been carried out before.

The method of path analysis is well suited for the examination of these issues.

METHODS

Procedure

In this article, we will give only a brief summary of the procedures employed and the findings involving the simple testosterone-behavior relationships (see 4, 5 for details). The main focus here is on the new and extended analyses, involving the two basic issues mentioned above.

Grade-9 Measures. The subjects were 58 healthy boys, 15–17 yr old, with a median age of 16. They were selected from the public school districts of Solna, a suburb in the metropolitan area of Stockholm in Sweden, to provide a roughly representative sample of the total male student population of the ninth grade (about 275 boys). The boys provided two sets of blood samples (separated by approximately 1 m) for plasma testosterone assays. The test-retest reliability or the stability of the individual differences, as expressed in the correlations between the two sets of measurements, was 0.63. The reliability of the individual average testosterone levels was 0.77 (Spearman-Brown corrected). The mean testosterone value for the whole group was 544 ± 141 ng/100 ml (range 197–901 ng/100 ml). Three of the boys were in Tanner Pubertal Stage 3, nine in Stage 4, and 43 in Stage 5 (adult), according to pubic hair development. The correlation between pubertal stage and testosterone level was 0.44.

Approximately 1 month before the blood samples were drawn, the subjects completed a number of personality inventories. Several scales, including the two scales of Olweus Aggression Inventory (6), Verbal Aggression and Physical Aggression (below), were used to tap various aspects of aggressive reaction patterns. In the path analysis, these two scales were combined into a composite, called Provoked Aggressive Behavior Grade 9. Its internal consistency reliability (alpha) was 0.74.

Peer ratings gave information on the boys' habitual level of aggressive behavior. Three dimensions were combined into a composite: Start Fights (unprovoked physical aggression against peers), Verbal Protest (verbal aggression against teachers), and Verbal Hurt (unprovoked verbal aggression against peers). This composite was called Unprovoked Aggressive Behavior Grade 9 in the path analysis. It has been used in a number of studies as a broad measure of aggressive, destructive behavior (e.g., 5, 7, 8). The reliability of this composite was 0.91.

In addition, data on physical variables such as height, weight, chest circumference, and pubertal stage were collected in a physical examination.

Earlier Measures. Data on the two basic aggression dimensions, Provoked Aggressive Behavior (self-reports) and Unprovoked Aggressive Behavior (peer ratings), were available for the subjects when they were in Grade 6 as well. For these variables, the designation Grade 6 was added to the variables names.

To provide detailed information about the boys' temperamental characteristics and rearing conditions during childhood, extensive, retrospective interviews were carried out with the mothers and fathers (independent of each other). This was done when the boys were 13 yr old. Analysis of the measurement characteristics of the interview data indicated that, generally, the information was reliable, accurate, and relatively free from biases of different kinds.

In the previous analysis (5), four variables were found to be central in a causal model for the development of an aggressive reaction pattern in a boy. These variables, to be included in the present path analyses, were: a) Mother's Negativism, the principal caretaker's basic emotional attitude to the boy during early years; b) Boy's Temperament, a composite of the boy's general level of activity and the intensity of his temperament (calm to hot tempered) in early years; c) Mother's Permissiveness for Aggression, the principal caretaker's degree of permissiveness or laxness with regard to aggressive behavior on the part of the boy; and d) Mother's and Father's Use of Power-Assertive Methods, in particular, physical punishment and strong affective reactions such as threats and violent outbursts.

A number of other potentially causal variables were examined in the context of this earlier analysis, but were found to be of negligible importance (see 5 for details).

The correlation matrix for the variables used in the causal models (to be presented) is given in the Appendix.

THE SIMPLE TESTOSTERONE-BEHAVIOR RELATIONSHIPS

The basic finding of the study was a substantial correlation between testosterone and each of the two scales of the Olweus Aggression Inventory, Verbal Aggression ($r = 0.38$) and Physical Aggression ($r = 0.36$). The simple composite of these two scales, Provoked Aggressive Behavior Grade 9, correlated 0.44 with testosterone.

Closer analysis of the individual items of the verbal and physical aggression scales revealed an interesting pattern: It was primarily items involving a response to provocation, including threat or unfair treatment, that showed a clear correlation with testosterone levels (Table 1).

The first eight items of Table 1 all contain an element of provocation by adults or peers. The correlations with testosterone were quite high for several of these items, considering the fact that the reliability of individual items is generally rather low. Conversely, the correlations for the last two items, which do not imply provocation, were negligible.

In addition, the only peer-rating scale containing an element of provocation, Verbal Protest, showed the highest correlation ($r = 0.24$) with testosterone. The wording of this rating dimension was as follows: "When a teacher criticizes him, he tends to answer back and protest." The correlation of testosterone with the composite of the three peer-rating dimensions, Unprovoked Aggression Behavior Grade 9, was 0.21.

To summarize these findings, we concluded that dimensions reflecting intensity and/or frequency of aggressive responses to provocation and threat appeared to be most clearly and directly related to testosterone. Other dimensions measuring unprovoked physical or verbal aggression and aggressive attitude or impulses also showed positive but weaker correlations with testosterone.

TABLE 1. Correlation Between Testosterone Levels and Individual Items from the Verbal and Physical Aggression Scales[a]

Item	Correlation coefficient, *r*
Verbal aggression	
When an adult is unfair to me, I get angry and protest.	0.18
When an adult tries to take my place in a line, I firmly tell him it is my place.	0.24
When a teacher criticizes me, I tend to answer back and protest.	0.33
When a teacher has promised that we will have some fun but then changes his (her) mind, I protest.	0.19
When an adult tries to boss me around, I resist strongly.	0.33
Physical aggression	
When a boy starts fighting with me, I fight back.	0.33
When a boy is nasty with me, I try to get even with him.	0.37
When a boy teases me, I try to give him a good beating.	0.15
I fight with other boys at school.[b]	0.05
I really admire the fighters among the boys[b]	0.11

[a] $n = 58$.
[b] These items do not contain a clear element of provocative challenge.

Testosterone and Frustration Tolerance

Another result of interest was the positive correlation ($r = 0.28$) between testosterone levels and a self-report scale called Lack of Frustration Tolerance. This scale contained only three items, all of them focusing on the boys' habitual level of impatience and irritability: 1) "I become easily impatient and irritable if I have to wait," 2) "Others say that I easily lose patience," and 3) "I become easily impatient if I have to keep on with the same thing for a long time." The internal consistency (alpha) reliability of this short scale was 0.59. The result above suggested that adolescent boys with higher levels of testosterone tended to be habitually more impatient and irritable than boys with lower testosterone levels.

Testosterone and Other, Non-Aggressive Dimensions

It is also important to note that testosterone correlated very weakly or not at all with a number of other behavior dimensions included in the study. None of the correlations was higher than ± 0.15 with any one of the following dimensions: Extraversion, Psychoticism, Feelings of Maladjustment and Inadequacy, and several indicators of state and trait anxiety.

CAUSAL ANALYSES

Path analysis implies that the researcher, on the basis of previous research and theoretical considerations, formulates a model that is intended to represent an approximation of the hypothetical causal relations among the variables included. The model is written as a set of structural equations and is generally also portrayed in a path diagram, with straight unidirectional arrows indicating the causal influence of one variable on another. In general, ordinary path analysis is restricted to recursive models involving no reciprocal causations or feedback loops. Using multiple regression techniques, one can estimate the

parameters of the equations and assess the adequacy of the model.

A crucial aspect of a path model is the causal ordering of the variables. In the present case, in which different variables or sets of variables by and large cover different time periods, the causal ordering of the variables is fairly straightforward: The principal caretaker's basic emotional attitude to the boy (Mother's Negativism in the figures) and the Boy's Temperament both refer to early childhood, whereas the parents' disciplinary techniques (M's and F's Use of Power-Assertive Methods and M's Permissiveness for Aggression) relate to somewhat later periods in the child's life. The Grade-6 and Grade-9 variables were measured at the modal ages of 13 and 16, respectively. On the basis of animal research and theoretical considerations, testosterone was assumed to be causally prior to Low Frustration Tolerance Grade 9, which in turn was assumed to be a causal antecedent to the two aggression dimensions as measured in grade 9 (see Figs. 1, 2).

For the present analyses, we started by postulating causal relations between each variable and every other variable farther to the right in the path diagram. In addition (as stated above), the causal order between the three Grade 9 variables was assumed to be Testosterone-Low Frustration Tolerance-Aggressive Behavior, and we postulated all three possible causal paths between them. Using the criterion for retaining a path coefficient specified below, some paths were eliminated (set to zero) in the empirical analyses, thus giving the more "final" models portrayed in Figures 1 and 2.

It should also be noted that no causal relation was assumed for two pairs of variables: between Mother's Negativism and Boy's Temperament, and between Mother's and Father's Use of Power-Assertive Methods and Mother's Permissiveness for Aggression. In these two cases, the two variables referred to approximately the same time period, and it was assumed that their covariation was noncausal (see 5). Curved lines without arrowheads are used to indicate a noncausal relation in the path diagram, and the associated coefficients are (zero order) correlation coefficients.

The coefficients beside the unidirectional straight arrows in the path diagrams (see Figs. 1 and 2) are path coefficients, standardized partial regression coefficients (betas), which express the direct causal effect of one variable on the other, when all other variables are controlled or held constant. Omission of an arrow between two variables (such as between Mother's Negativism and Mother's Permissiveness for Aggression) means that the path coefficient for this relationship was too small to be retained in the model. Because our sample was of limited size, the choice was made to keep path coefficients of variables that, in a step-wise regression, accounted for at least 1% of the variance in the relevant dependent variable (the same procedure was followed in 5).

R (just below the ultimate dependent variable, farthest to the right) is the multiple correlation, and R squared stands for the amount of variance "explained" or predicted in the ultimate dependent variable by the causal variables included in the model.

A useful feature of path analysis is that it also permits estimation of indirect causal effects. There is an indirect effect of one variable, say Testosterone Grade 9, on another, say Unprovoked Aggressive Behavior Grade 9 (see Fig. 2), when Testosterone has a causal effect on an intervening variable, Low Frustration Tolerance Grade 9, which in turn exerts a causal influence on

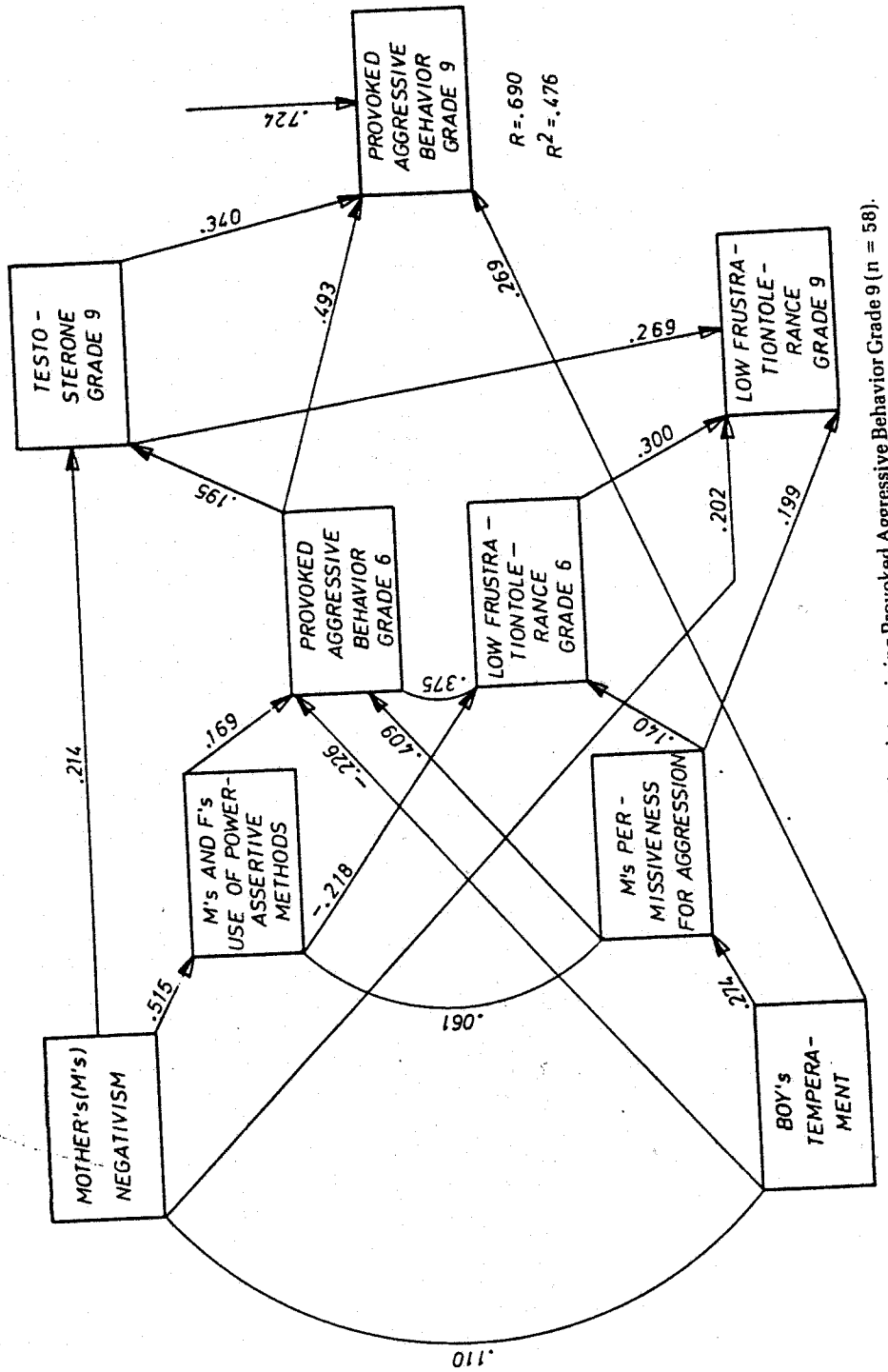

Fig. 1. Causal (path) diagram of variables determining Provoked Aggressive Behavior Grade 9 (n = 58).

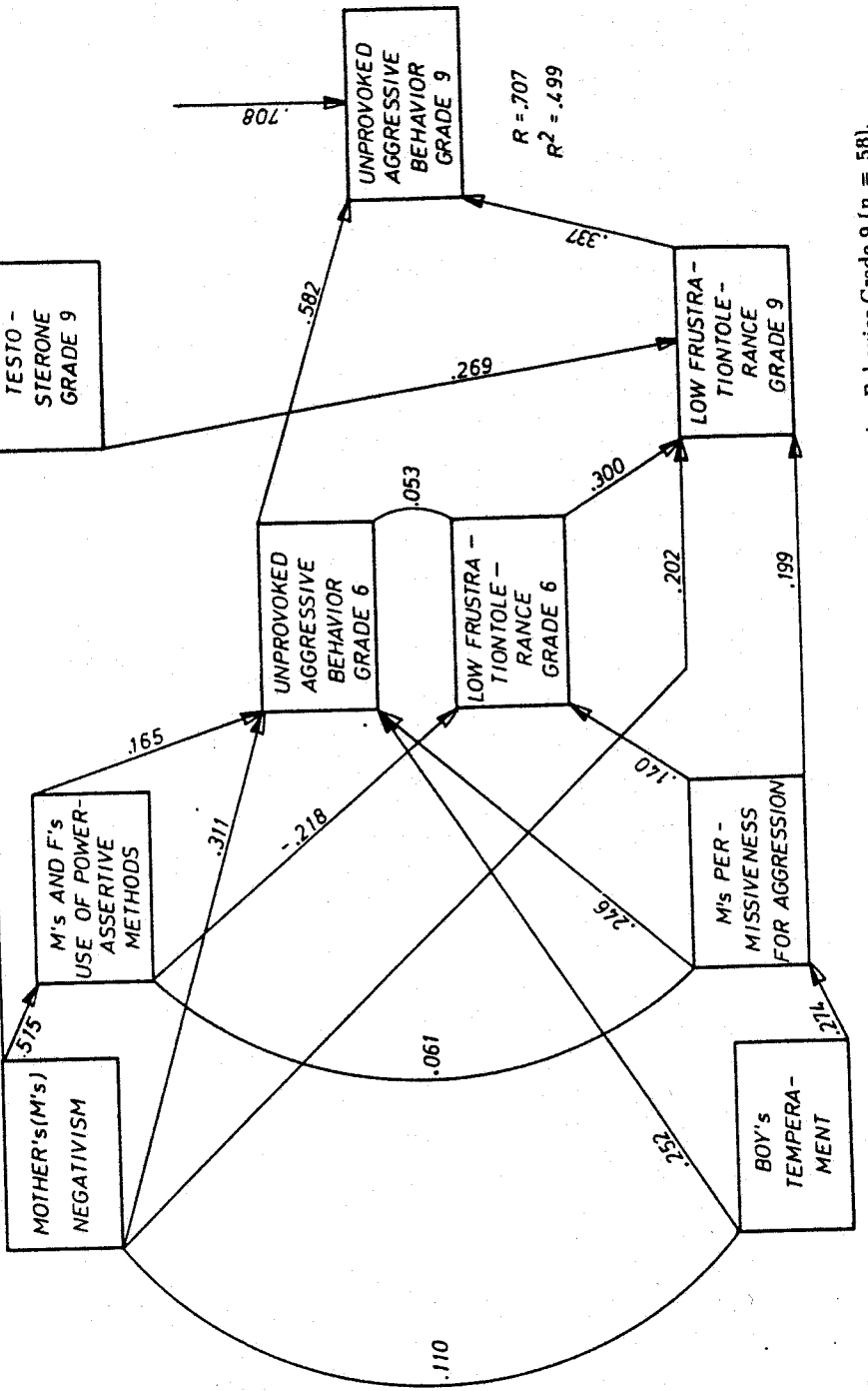

Fig. 2. Causal (path) diagram of variables determining Unprovoked Aggressive Behavior Grade 9 (n = 58).

Unprovoked Aggressive Behavior Grade 9. In other words, when there is an indirect effect, part or all of the effect of one variable on another is mediated by an intervening variable. The magnitude of the indirect effect is obtained through multiplication of the path coefficients involved—in the present case 0.269 × 0.337 = 0.091.

We want to emphasize that, in the present context, the chief aim of including the temperamental and child rearing variables in the model was to control the testosterone-aggression relationships for other, causally prior variables. As mentioned, if the relationship between testosterone and aggression holds up, wholly or partially, when a number of antecedent, potentially causal variables are included in the model, the likelihood that testosterone has a causal, nonspurious effect on aggression is substantially increased. Since the possible effects of the antecedent variables are of minor interest in their own right for the present purposes, we pay little attention to the left half of the path diagrams in Figure 1 and 2.

A more detailed discussion of the meaning and causal ordering of the childhood variables mentioned above can be found in Olweus (5). More general information about path analytic techniques is available in a number of textbooks and general expositions (9–13).

Testosterone and Provoked Aggressive Behavior

The main results from the path analysis are presented in Figure 1.

The substantial coefficient ($\beta = 0.340$) for the path leading from Testosterone Grade 9 to Provoked Aggressive Behavior Grade 9 suggests that testosterone exerts a direct causal influence on this aggression variable, reflecting responsiveness to provocation and threat. The original correlation of 0.44 was only moderately reduced when the causally prior variables were controlled for. Given the causal ordering implied in the model, this result indicates that a higher level of testosterone leads to an increased readiness to respond vigorously and assertively to provocations and threats.

The figure also shows that testosterone lowered the boys' frustration tolerance at Grade 9 ($\beta = 0.269$). It should be noted, however, that Low Frustration Tolerance Grade 9 had no effect on the provoked aggression variable. This is in contrast with the results to be discussed below.

As could be expected, the largest path coefficient leading to Provoked Aggressive Behavior Grade 9 ($\beta = 0.493$) came from the variable itself, which had been measured 3 yr earlier. This indicates a moderate degree of stability over time ($r = 0.539$) in this variable. However, the relative stability of the variable did not prevent testosterone from having a substantial effect on the Grade-9 behavior, as discussed above.

Testosterone and Unprovoked Aggressive Behavior

The pattern of findings is shown in Figure 2. It should be noted that testosterone in this case had no direct effect on the ultimate dependent variable, Unprovoked Aggressive Behavior Grade 9. There was, however, a clear indirect effect (0.269 × 0.337 = 091), with Low Frustration Tolerance Grade 9 as a mediating variable. The stability of the ultimate dependent variable was somewhat higher in this case ($\beta = 0.528$; $r = 0.623$) than in Figure 1.

We want to call attention to two additional points. First, there were no paths

from Unprovoked Aggressive Behavior Grade 6 or Low Frustration Tolerance Grade 6 to the testosterone variable. Thus, the boys' level of testosterone were not determined by these causally prior Grade-6 variables.

Second, there was only a very weak correlation between Unprovoked Aggressive Behavior and Low Frustration Tolerance at Grade 6 ($r = 0.053$), whereas the correlation between them was considerably higher at Grade 9 ($r = 0.408$). An association had thus emerged in the period from Grade 6 to 9 and, according to the path-analytic results, testosterone was the major variable accounting for the association.

In sum, the path-analytic results (Figure 2) suggest that a high level of testosterone in puberty made the boys more impatient and irritable, which in turn increased their readiness to engage in aggressive behavior of the unprovoked and destructive kind (to start fights and say nasty things without being provoked). In contrast with the findings for Provoked Aggressive Behavior (Fig. 1), the effect of testosterone was indirect in the present case.

Although we did not use statistical significance as a criterion for retaining a path coefficient in the causal models, it should be noted that all coefficients discussed here were significant at the 0.01 level, with the exception of the coefficient for Testosterone Grade 9 to Low Frustration Tolerance Grade 9, which was significant at the 0.05 level.

The Possible Role of Pubertal Stage

The clear correlation ($r = 0.44$) between Testosterone Grade 9 and pubertal development (according to pubic hair development) raises the question whether the correlations between testosterone on one hand, and the dimensions of aggression and low frustration tolerance on the other, are spurious. Can the relationships be largely explained by pubertal stage as a common causal factor? We examined this possibility by including pubertal stage in the causal model (after the Grade-6 variables but before testosterone and the other Grade-9 variables).

When the two path analyses were repeated with pubertal stage included, the path coefficients relevant to our discussion were practically unchanged. The effects to testosterone were thus largely independent of the boys' degree of pubertal development.

DISCUSSION

We can now return more specifically to the two issues raised in the introduction. Given the causal models portrayed in Figures 1 and 2, it can be concluded that testosterone had causal effects on two forms of aggressive dimensions, Provoked and Unprovoked Aggressive Behavior (Grade 9), even when a number of causally prior variables were controlled for. However, these effects were of different strength and of a different kind.

With regard to Provoked Aggressive Behavior, the analyses indicated that testosterone had a relatively marked and direct causal effect. As previously stated, this result implies that, in adolescent boys, an elevated level of testosterone creates a heightened tendency to respond aggressively and assertively to provocation and threat.

Considering the boys' readiness to engage in aggressive-destructive behavior, it is obvious that testosterone was only one of many possible causal factors, and one with indirect and fairly weak effects. The analyses indicate that high levels of testosterone affect to some extent the prob-

ability that the boys will initiate aggressive-destructive behavior by making them more impatient and irritable, that is, via lowered frustration tolerance.

In judging the strength of the relationships, it is important to realize that the reported path coefficients, based on fallible variables, were underestimates of the true effects. In addition, it should be noted that testosterone exerted its effects largely independent of other causal factors. This means that testosterone made a relatively unique contribution to the prediction of the aggressive behavior dimensions, in particular Provoked Aggressive Behavior.

It is of interest to compare these findings with results from animal research. Summarizing a large number of studies on the psychobiology of aggression, Moyer (2) distinguished six major classes or dimensions of aggressive behavior in animals: predatory, intermale, fear-induced, irritable, maternal, and sex-related aggression. He concluded that two of these dimensions were likely to be under androgen control, namely irritable and, in particular, intermale aggression. So far as we know, circulating levels of testosterone have not been found to be systematically related to other behavioral dimensions in animals (with the exception of sexual behavior).

The most potent releaser of intermale aggression is the presence of a male conspecific to which the animal has not become habituated (2). In animals, this kind of reaction is found exclusively among males. In several species, it does not appear, or at least is not fully developed, until puberty. Without stretching the imagination, we can easily see clear parallels between this behavior pattern and the kind of vigorous, assertive aggression in response to threat and provocation that is implied in the variable of Provoked Aggressive Behavior.

The second class of aggressive behavior identified by Moyer as being under androgen control—but less so than intermale aggression—is irritable aggression. This is a much more comprehensive and diffuse category of aggressive behavior with less clear releasers. However, frustration is regarded as one important class of antecedents to this behavior pattern. From Moyer's description, it is easy to find similarities between this kind of behavior pattern in animals and the characteristics of impatience and irritability implicated in the variable of Low Frustration Tolerance, which in turn affected the boys' readiness to engage in aggressive-destructive behavior.

Obviously, our results do not imply that the behavior patterns we have found to be under androgen control depend on circulating levels of testosterone at puberty for their appearance. This clearly cannot be the case, since these patterns existed and were highly differentiated between individuals already at Grade 6. However, the findings suggest that circulating testosterone levels can influence the relative strength or intensity of these reaction patterns at puberty (and possibly later) to a significant degree.

We do not want to overemphasize the parallels between our testosterone-behavior relationships and those identified in animal research (which, by and large, has not focused directly on the relationship between individual differences in testosterone and behavior). It is nonetheless striking that the two variables most strongly associated with testosterone in our study were those whose apparent counterparts in animals were under testosterone control, according to Moyer (2). In this context, it should be recalled that our study included a number of other behavioral or personality dimensions (4)

that were less closely or not at all related to testosterone.

As stated in our first report on the testosterone-behavior relationships (4), the conditions surrounding the present study were generally favorable. However, with regard to the extended analyses and interpretations offered here, it is appropriate to issue a caution. Even if a considerable number of variables were included in the path models—which is certainly desirable from a "control" point of view—there is always the possibility that one or more important, causally prior variables have been omitted. Addition of such variables to the models might lead to a change in the causal structures. In view of this fact and the moderate size of the sample, the findings should be regarded as tentative until they have been replicated in other samples.

To avoid misinterpretation of our findings, we want to emphasize that a theoretical position that recognizes the possibility of a hormonal basis for animal and/or human behavior patterns, by no means excludes learning experiences as important determinants of the behavior in question.

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APPENDIX Correlations of Variables in the Causal Models (decimal points omitted).

	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
x_1	11	51	09	14	−10	24	26	08	45	29
x_2		02	24	−07	−03	−03	−05	30	34	23
x_3			06	19	−21	01	02	07	34	21
x_4				36	13	−05	24	22	35	37
x_5					38	23	24	54	35	34
x_6						−08	28	09	05	14
x_7							28	44	11	21
x_8								21	12	41
x_9									37	45
x_{10}										62

Note: x_1 = Mother's (M's) Negativism, x_2 = Boy's Temperament, x_3 = M's and F's Use of Power-Assertive Methods, x_4 = M's Permissiveness for Aggression, x_5 = Provoked Aggressive Behavior Grade 6 (Fig. 1), x_6 = Low Frustration Tolerance Grade 6, x_7 = Testosterone Grade 9, x_8 = Low Frustration Tolerance Grade 9, x_9 = Provoked Aggressive Behavior Grade 9 (Fig. 1), x_{10} = Unprovoked Aggressive Behavior Grade 6 (Fig. 2), x_{11} = Unprovoked Aggressive Behavior Grade 9 (Fig. 2).

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