Photographic Analysis of Control Responses of Motorcycle Operators

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The purpose of the research described in this paper was to identify the precise nature of the control responses required of motorcycle operators in turning, stopping, avoiding collisions, and surmounting an obstacle. An earlier analysis of the motorcycle operator's task (1) revealed that there are a number of questions about the nature of the responses required of operators in carrying out these tasks.

METHOD

Two highly experienced motorcycle road racers carried out each of the four maneuvers. Their performance was recorded by two Super 8 cameras, one mounted beside the motorcycle's path of travel and one mounted at the rear of the motorcycle. Super 8 photography was found to offer an inexpensive means of recording a wide array of operator and vehicle responses. The equipment proved extremely durable, surviving a number of falls without damage.

Cameras

The first camera was mounted on a tripod in such a position as to keep the operator and motorcycle suitably framed during each maneuver. In turning maneuvers, it was positioned close to the axis of the turn. It recorded the motorcycle's position on the path and its pitch angle; front- and rear-wheel rotation (locked versus rolling); the operator's body position (seated versus standing), body angle, and foot position (on or off pegs); and the motorcycle's deviation from its path.

The second camera was mounted on a lightweight frame that extended 1 m (3 ft) to the rear of the motorcycle. It was focused on a display panel that was mounted directly behind the operator. The display panel held a set of pointers, each of which was connected to one of the vehicle's controls. The position of the pointer indicated the position of the corresponding control. The operator's upper body, the motorcycle's speedometer, and the horizon were also captured by the rear camera. In all, the rear camera recorded the positions of the front and rear brakes, the throttle position, the clutch position, the steering angle, the velocity, the motorcycle's roll angle, and the operator's body angle and body position.

Maneuvers

Each maneuver was performed by each operator on a moderate-sized (500-cc) and on a small-sized (100-cc) motorcycle. To allow for filming problems, each run was performed three times. The process of data reduction involved reviewing each selected film frame by frame and measuring operator and vehicle responses. All responses were plotted along a common timeline to provide a graphic profile of each maneuver.

The maneuvers performed were as follows:

Turning

Turning maneuvers involved a series of 90-deg curves with radii of 3, 6, 9, and 15 m (10, 20, 30 and 50 ft). Each curve was taken at a specific speed. In each case, the speed was set as close as possible to the maximum at which the curve could be negotiated. Turning maneuvers were performed on both wet and dry surfaces.

Stopping

The stopping maneuver consisted of a series of straight-line braking exercises performed at 40 and 61 km/h (25 and 38 mph), over both dry and wet pavement. Each maneuver was performed by using three different techniques for applying the rear brake:

1. Locked. The rear wheel was locked and the motorcycle brought to a skidding stop.
2. Controlled. The rear brake was applied as firmly as possible without locking the rear wheel.
3. Modulated. The rear wheel was alternately locked and released.

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Avoiding Collisions

In a collision-avoidance maneuver, the operator approached a barrier through a chute of traffic cones. On reaching the end of the chute, he was to make a quick turn to avoid the obstacle. The operator was free to use any combination of braking and turning.

Surmounting an Obstacle

The maneuver to surmount an obstacle took place along the edge of an asphalt surface where there was a 10.2-cm (4-in) drop-off to a paved shoulder. A series of barriers forced the operator to drive onto the paved shoulder and then return to the asphalt surface. The arrangement was designed to require the operator to approach the asphalt surface at the smallest angle at which it could be safely surmounted.

RESULTS

Maneuver profiles varied considerably from one trial to the next. The intraindividual variability was as great as that between individuals. However, sufficient commonality was found across trials and riders to support the following statements of general findings.

Turning

Turning a motorcycle involves achieving a close coordination between the motorcycle's angular velocity and the roll angle. Both motions are controlled almost entirely through adjustment of the steering angle. It is particularly noteworthy that neither the operator's body angle nor body position was substantially involved in producing the motorcycle roll required to maintain balance through a turn. Approximately half of the turns were initiated through a "countersteer," that is, a slight deflection of the front wheel away from the direction of the intended turn. The countersteer was generally about 2 deg in amplitude, with durations ranging from $\frac{1}{8}$ s to almost a full second. Where no countersteer appeared, it was hypothesized that the required roll developed out of the normal roll oscillations that characterize straight-line operation.

Most operators leaned their bodies slightly in the direction of the intended turn as they began the turn. The small amount of leaning involved, coupled with the fact that it did not appear to be closely correlated with the roll of the motorcycle, suggests that it had little direct effect on the motorcycle's roll angle. It may only reflect the operator's anticipation of a turn. A similar phenomenon occurred in ending the turn, where there was a slight reduction in the body angle, just as the motorcycle began its return to an upright position. This change in body angle could not have helped in any way to straighten up the motorcycle.

Once a turn is initiated, stability is maintained by coordinating velocity and steering angle so that the outward force of the turn counters the gravitational force acting upon the operator. Variations in steering, throttle application, and braking were observed during turns. The frequency and amplitude of these variations were less for the two experienced riders than among novices attempting the same maneuvers.

The motorcycle is brought back to an upright position by adjusting the steering angle so as to achieve a high rate of turn and an excessive outward force. In large-radius turns, ending the turn was associated with a definite change in the steering angle. In turns with a short radius, the necessary steering angle was attained through a continuation of the original steering input. In other words, the operator started to come out of the turn as soon as he was in it.

Stopping

The shortest stopping distance was achieved by maximum application of the rear brake to the locked position and controlled application of the front brake. The sooner and more firmly the front brake was applied, the shorter was the stopping distance. There was no support for the theory that the rear brake should be applied before the front brake. In most instances the rear brake was applied first, slightly ahead of the front brake, but this appeared to be a result of the operator's and vehicle's control mechanisms rather than the result of any attempt to apply one ahead of the other.

Modulating application of the rear brake or controlling it to prevent the rear wheel from locking produced longer stopping distances. This was true regardless of initial velocity or the degree of surface friction. Because the rear wheel contributes less than 30 percent of the braking power, it did not appear likely that differences in application of the rear brake could account for the observed differences in stopping distance. The results were attributed to the fact that locking the rear wheel allows the operator to devote total attention to adjustment of the front brake and thus produces better application of the front brake.

Surprisingly, stopping distances on dry pavement were not appreciably different from those obtained when the surface was wet. It is hypothesized that caution in application of the front brake resulted in stopping distances on dry surfaces that were above the minimum obtainable. When the surface was wet, it became unnecessary to reduce the level of brake application.

Avoiding Collisions

In attempting to avoid an obstacle in the path of the motorcycle, operators turned and braked simultaneously. Slowing the motorcycle allowed more time to achieve a greater turning arc and thus a greater change in lateral position.

The greatest danger in braking during an obstacle-avoidance maneuver was locking of the rear wheel. This did not occur among the expert riders but was observed among nonexperts performing the maneuver. When the rear wheel is locked in a turn away from an obstacle, the operator is forced to turn toward the obstacle in order to maintain balance. In the case of a real obstacle, such as an automobile, such a turn could be extremely hazardous. It appears advisable to avoid use of the rear brake entirely during the collision-avoidance maneuver.

Surmounting an Obstacle

Surmounting an obstacle in the motorcycle's path requires (a) a quick application of the throttle to achieve a rearward weight shift and thus reduce the load on the front wheel and (b) rising on the foot pegs to keep from being thrown from the seat as the rear wheel strikes the obstacle. The motorcycle must be kept upright to avoid capsizing.

When the obstacle is parallel to the path of the motorcycle (e.g., a curb), the motorcycle must approach the obstacle at a sufficient angle to allow the front wheel to climb the obstacle. With an obstacle 10.2 cm (4 in) in height, the minimum safe angle of attack was found to be 35 to 45 deg. In a few instances, the obstacle was surmounted at angles as small as 20 deg. However, in such instances, the rear wheel was dragged sideways for a short distance. When it did finally climb the obstacle, it caused the motorcycle to lurch ahead. In one instance, this caused a fall. No attempts were made to climb the obstacle at an angle less than 20 deg. Had such an attempt been made, it is likely that the front wheel would have been deflected sideways rather than climbing the obstacle. The result would have been a loss of steering control resulting in an immediate fall.

REFERENCE

1. National Public Services Research Institute. Motorcycle Task Analysis. Motorcycle Safety Foundation, Elkridge, Md., Oct. 1974.