EFFECTS OF IMPACT LOCATION ON SOFTBALL BAT VIBRATIONS AND DISCOMFORT

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The "sweet spot" of a baseball or softball bat has been generally described as the most effective hitting area of the bat (Noble and Eck, 1986). Also, impacts on the sweet spot do not shock or hurt the hands, and the player feels the bat gliding smoothly through the impact. The location of the center of percussion (COP) and the node of the fundamental vibrational mode have been proposed as the primary determinants of the sweet spot (Brancazio, 1984). In most bats, the distance between these points is between two and four centimeters. Noble and Walker (1994) found no difference between these two cites regardng discomfort and annoyance from impacts. However, proceures have been developed to displace the COP to other points on the bat, resulting in an implement with the COP and fundamental vibrational node a considerably greater distance apart (Noble and Eck, 1985). A COP displacement nearer the barrel end of the bat is thought to result in a greater post-impact ball velocity because of the largely rotary bat movement prior to and during impact. Hitters must adjust their swing so the COP impacts with the ball if these beneficial results are to be realized. The desired adjusment in the swing will naturally occur only if the COP impact is comfortable to the hitter. However, vibrations produced by impacts on the displaced COP could interfere with efforts to appropriately adjust the swing if they are uncomfortable or painful. More information is needed regarding the relative annoyance of impacts on the node and COP when these locations are farther apart than with conventional bat models.

The purpose of this study was to compare vibrational characteristics and perceptions of discomfort resulting from impacts on the COP and fundamental vibrational node of bats with varying COP-node distances.

METHODS

Seventeen adult skilled slow-pitch softball players (9 females, 8 males) aged 25-40 years participated in this study. All subjects had played organized slo-pitch softball for at least three years.

Subjects used four bats 34 in (.864 cm) in length and with a barrel diameter of 2.25 in (.057 m). All bats were made with CU31 alloy using the same manufacturing procedures, had the same wall thickness, and had no exterior distinguishing marks. The bats were different with respect to two features: (a) two bats had hollow aluminum knobs (21.9 g) and two bats had solid steel knobs (190.8 g), resulting in very different locations of the COP and vibrational characteristics; and (b) two bats had short barrels and two bats had long barrels, causing more pronounced changes in the fundamental frequency. These bats are designated as follows: (1) AS - aluminum knob, short barrel. (2) SS - steel knob, short barrel; (3) AL - aluminum knob, long barrel; and (4) SL - steel knob, long barrel. The desired differential characteristics were achieved as the four subject bats were very different with regard to fundamental frequency (SS=129 Hz. AS 151 Hz, SL=245 Hz. AL=300 Hz) and distance between the COP and distal node of the fundamental mode (SS=.097 m. AS=.023 m. SL=.106 m, AL=.025 m).

Apparatus and procedures previously described by Noble and Walker (1994) were used to determine mechanical and vibrational bat characteristics. A wood mounting and framework were constructed to enable a Jugs ball throwing machine to accurately propel a ball through a nine-inch (22.9 cm) (inside diameter) polyvinyl chloride pipe a distance of three feet (91.4 cm) to a specific part of a hand-held bat. The bat was held firmly against a slot cut into the end of the pipe by the subject so that the ball impacted at the desired point. Two onedimensional foil strain gages were bonded to opposite sides of each bat at a point one-third of the distance from the location of the hands to the COP of the bat. The strain gauge of the bat in use was attached to an analog-to-digital converting interface board of a microcomputer wherein the output was sampled and stored for subsequent analysis. Two light sources aimed at corresponding sensors imbedded in the walls of the pipe were used to determine pre-impact ball velocity and to trigger the onset of data collection. Data collection began 5 msec prior to impact and continued for 25 msec. Thus, the sampling period was 30 msec.

Each subject held each bat firmly against the polyvinyl chloride pipe for each trial. Two softballs were propelled at a speed of 25 m/s (82 mph) onto the bat at the following three sites: (1) center of percussion (COP), (2) node of fundamental vibrational mode, and (3) a point midway between the COP and .node. The order of bat usage and impact site were rotated. Ball velocity was recorded for each impact while digitally converted data on bat vibrations were recorded for one impact on each location. Also, responses to a series of questions regarding perceptions associated with impacts were obtained and recorded. All tests were completed within one 30-minute testing session. After each pair of impacts, subjects were asked the following questions:

(1) Did you experience vibration from the impact?

(2) Did you feel shack from the impact?

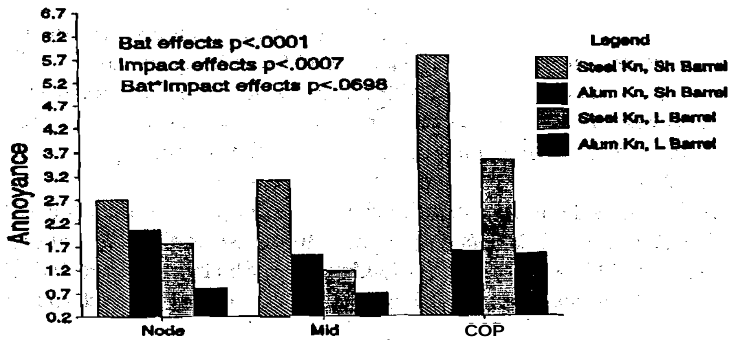
(3) How uncomfortable was the shock or vibration from the impact? (0=none, 1=slight, 2=moderate, 3=severe).

After all impacts, subjects were asked to select the impact location that was most and least comfortable and the bat that was most and least comfortable. The purpose of the first two items was to determine if subjects could perceive the difference between COP impacts. which were expected to excite both the fundamental and first overtone vibrational modes, and impacts on the fundamental node, which were not expected to excite the fundamental vibrational mode, but would produce a reaction impulse on the hands (Noble and Eck, 1986). Each subject was asked to read and sign a statement of informed consent prior to participation.

RESULTS AND DISCUSSION

Chi-square tests for independence on questionnaire responses indicated that significantly greater incidence of both shock and vibration were associated with bat SS and signifiantly lesser incidence of shock and vibration were associated with bat AL. Also, the greatest incidence of both shock and vibration occurred with impacts on the COP and less incidence of both shack and vibration occurred with impacts between the node and COP. However, the Chi-square test for independence was not significant at the .01 level for either of these comparisons. Thus, subjects did not seem to differentiate between vibrations caused by COP impacts and the impact impulse, or shock, caused by impacts on the fundamental node. Group comparisons of the weighted sums (0=none, 1=slight, 2=moderate, 3=severe) of tallied responses from questionnaire items assessing the degree of discomfort from both shack and vibration associated with each impact were made using ANOVA. Results of this analysis are shown graphicly in Figure 1. Significant effects were found for both bat ($p<.001$) and impact location ($p<.01$). Ratings were significantly higher using bat SS than for all other bats. Ratings for bats AS, SL, and AL were not significantly different. Ratings were significantly higher for COP impacts than for impacts on the fundamental node. Interaction effects were not significant. Thus, it appears that COP impacts produced more discomfort, or annoyance than impacts on the fundamental node for all bats.

Figure 1. Comparison of annoyance means



The vibrational waveform associated with each impact was analyzed using power spectral analysis to identify the two frequency components with the greatest spectral density. These frequencies were labeled fundamental mode (lower) and first harmonic mode (higher). Fundamental and first harmonic frequencies as determined by power spectral analysis of waveforms resulting from impacts of the hand-held bats were slightly lower than these parameters determined under free-free boundary conditions. Deviations of from 1 to 12 per cent were noted, probably the result of dampening due to forces applied by the hands. These results are consistent with those from the little league baseball bat study by Noble and Walker (1994) in this regard and are consistent with the free-free model of a hand-held bat.

The peak excitation of the vibrational waveform and the two power coefficients were compared for each bat as well as for impact location using ANOVA. Peak voltages were significantly higher for bats SS and SL than for bats AS and AL. COP impacts produced significantly higher voltage output than impacts on the fundamental node. Interaction effects were not significant, indicating that these differences were consistent across bats.

Power of the fundamental mode was significantly higher for bat SS than for all other bats. These values were significantly higher for bat SL than for bats AL and AS. Bat*impact interaction effects were significant, indicating that location effects were not consistent across bats. Both main effects as well as interaction effects are probably due to the widely varying distances among the intended impact locations for different bats. Analysis of waveform characteristics of impacts relative to the distance of the impact from node locations revealed a high relationship between impact-node distance and power coefficients. These results indicate that, while knob end loading may produce some beneficial effects, this procedure results in a bat with a lower fundamental frequency and a greater node-COP distance - characteristics causing the bats to be less comfortable and less acceptable to the hitter.

Pearson Product Moment Correlations between questionnaire discomfort indexes and excitation characteristics (peak excitation, fundamental frequency, first harmonic frequency. and power coefficients for each frequency mode) were calculated for all impacts. Discomfort was significantly related to all five vibrational variables. The strongest relationship was with power of the fundamental frequency. as might be expected. Both fundamental frequency and first harmonic frequency were negatively correlated to discomfort. While previous research has shown a negative relationship between vibrational frequency and annoyance (Reynolds 'and others, 1977), we did not expect to find a significant relationship between these variables in this study because of the relatively small frequency range. The significant relationship could possibly due to two reasons: (1) bats with the lower frequencies had the greatest distance between the fundamental node and the COP, and (2) a tighter grip would result in increased dampening and a lower frequency. It is possible that a tighter grip would also result in greater discomfort.

CONCLUSIONS

The results of this study indicate that, for bats having large fundamental node-COP distances (greater than 9 cm), impacts on the fudamental node are more comfortable than impacts on the COP. Perceptions of discomfort are strongly and directly related to the degree of excitation of both the fundamental and first harmonic vibrational modes, which are in turn directly related to the distance from impact to the respective node.

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