Measuring Coach Effects in Archery Sport with Hierarchical Linear Modeling

Kai-Li Wang
Graduate Institute of International Sport Affairs, National Taiwan Sport University, Taoyuan, Taiwan
Email: elverz@ms8.hinet.net

Yun-Ci Ye
Department of Somatic and Sports Leisure Industry, National Taitung University, Taitung, Taiwan
Email: scanker1981@nttu.edu.tw

***Abstract*—Little quantitative research has been done on coaching effects. This is because scoring in sports games is often associated with teammates, adversaries, and referees. This paper attempts to initiate a probe into archery, whose scoring is relatively objective, to measure the coach effects in training. The score records, totally 6,044 pieces of data from 2270 players and 146 coaches, about standard outdoor target archery rounds in national archery competitions held between late 1997 and early 2007 in Taiwan were collected. The authors of this study managed to collect supplementary data of these players and coaches, including gender, seniority and educational background, etc. HLM (hierarchical linear modeling) analysis was performed by including the player-related data in the individual level of independent variables, and the coach-related data in the group level of independent variables with the 30-m archery game scores as the dependent variable. Results show that the coaching effect is non-ignorable because the intra-class correlation coefficient is high enough. We performed a further linear regression analysis of both individual level and group level. Results show that the coach effect is more important in the early-stage training. The training quality (measured by coach-player ratio) also seems considerable to training performance. The study result can serve as references for sport and physical education policy.**

***Index Terms*—archery, sports performance, coach effect, coach-player ratio, hierarchical linear modeling**

I. Introduction

Most of previous coaching effects studies on the influence of sportsmen's performance focus on psychology and sociology, showing the tendency to indirectly evaluate sportsmen by questionnaire survey [1]. Some of these studies go through the association between the coach's coaching behavior and the player's scores. Garland and Barry use the play time as the criteria (i.e. starter/lineup, dugout/bench player, backup player) for evaluating sports performance, finding out that the coach's coaching behavior has outstanding predictive power on the sports performance [2]. However, more researchers use the sports performance perceived by players as the dependent variable to predict the coach's coaching results [3], [4]. Some other studies using the players' satisfaction as the criterion for evaluating the coach's coaching behavior suggest that various facets of the coach's coaching behavior are associated with the players' satisfaction [5], [6]. For the coaching behavior, the Multi-dimension Model of Leadership (MML) – which is established using the Leadership Scale for Sports (LSS) designed by Chelladurai and Saleh [7] – is commonly used as the independent variable to assess the coach's coaching behavior. Results show that: the dimensions of 'training and instruction', 'democratic behavior', 'social support', & 'positive feedback' have the positive relationship with the players' satisfaction, while 'autocratic behavior' has the negative relationship.

There are some other studies focusing on the structural relationship: "coach's behavior — player's perception and memory — player's response evaluation" [8]. Especially highlighted is the confusion over the coach's objective behavior and the player's subjective perception as resulted from the players' self-assessment of coach's behavior in past studies. These studies observed, recorded and coded the coach's actual behavior by utilizing the Coaching Behavior Assessment System (CBAS). A post-game questionnaire survey on the players' perception and attitude was also conducted to analyze the influences among them. Results show that the player-perceived coach behavior explained most of the variances; in some studies, it even mediated the coach's actual behavior to a full extent [9], [10]. These studies shed light on how psychological and sociological studies can be limited by a questionnaire-based approach to measure coaching behaviors and coaching effects. The limitations include less objectivity and an overestimation of the association between coaching behaviors/effects.

Comparatively objective criteria for assessing coaching effects may include coaching time, number of instructions given to players, or other coach-specific variables (e.g. the coach's seniority and gender; the coaching stage to the player). In the past, few studies are available concerning the correlation of these variables with the actual sports performance. These easily-observable manifest variables used to be neglected as a moderator in the fields of psychology and sociology. Reasons may include the following situations: (1)

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Concerns over issues may vary. Observing only manifest variables (such as gender, seniority) is considered insufficient as the psychology and sociology focus on interpersonal interaction, teaching scenario, etc. (2) Better understanding of implicit variables such as attitude and motive, feeling requires a questionnaire survey to be conducted. The collection of questionnaire survey is quite costly, especially for longitudinal researches. Failure to address technical barriers or cost problems may cause doubts about the validity and reliability of data collected. Under such a circumstance, analyzing only the manifest variables may cause doubts about the accuracy of explained variances (especially when involved in cross-period data of coaches and players) as compared with typical psychology and sociology statistical analysis. (3) Failure to assess sports performance (the dependent variable) in an objective manner may also undermine the researcher's determination to collect data. The collection of large amounts of data on game scores for long periods of time, after all, is ever easy. The inclusion of unwanted information from evaluators (e.g. the influence by the judge) will undermine the possibility of such research.

To overcome the above difficulties, this paper will collect cross-period data from Taiwanese archery players by using Hierarchical Linear Modeling (HLM) for empirical study. The field of archery is chosen as the subject for its less sensitivity to the judge and the teammate, which can leave the objectivity of dependent variable to be neglected. Regarding independent variables, we collected as many as objective variables related to coach or player, including gender, seniority, identity and coach-player ratio. While this information may not be as microscopic as what is collected via questionnaire survey, an HLM-based analysis can serve to separate coach-specific variance form player-specific variance, thereby elevating the model's explanatory power.

II. Research Method

A. Statistical Method: Hierarchical Linear Modeling (HLM)

In many cases, individual observations on dependent variables come from 'nested' environments, for example, research in education, where HLM models have found their greatest application typically focus on the individual student [11]. The student, however, is part of a class, which is nested within a school belonging to a school district. This nesting of observations suggests that individual performance may be a result of both student-level attributes as well as, say, school-level qualities. Analogously, the game scores that archery players receive may be determined by player-level attributes as well as coach-level attributes. That is, players with the same level of skill may in fact have differing game scores if they follow different coaches, due to coach-specific effects. In order to separate out the player- and coach-level effects, the following econometric model for player game score can be considered:

$$Y_{ij} = \beta_{0j} + \beta_{1j}\,Gender_{ij} + \beta_{2j}\,Education_{ij} + \beta_{3j}\,Seniority_{ij} + \beta_{4j}\,Times_{ij} + \gamma_{ij} \quad (1)$$

where:

Y_{ij} = player i's 30-m archery game scores, on coach j,
$Gender_{ij}$ = player i's male or female, on coach j,
$Education_{ij}$ = player i's elementary school, junior high, senior high, or university, on coach j,
$Seniority_{ij}$ = player i's years of seniority, on coach j,
$Times_{ij}$ = player i's times of participation in games, on coach j,
γ_{ij} = stochastic error term, $\gamma ij \sim N(0, \sigma 2)$ is assumed.

Equation (1) is referred to as the 'level one model' , providing a specified model for 30-m archery game scores at the player level.

A hierarchical linear modeling further assumes that the coefficient β_{0j} to β_{4j} can be modeled as functions of coach-level effects, for example:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\,Gender_j + \gamma_{02}\,Primary_j + \gamma_{03}\,Junior_j + \gamma_{04}\,Senior_j + \gamma_{05}\,CP1997_j + \gamma_{06}\,CP1998_j + \gamma_{07}\,CP1999_j + \gamma_{08}\,CP2000_j + \gamma_{09}\,CP2001_j + \gamma_{010}\,CP2002_j + \gamma_{011}\,CP2003_j + \gamma_{012}\,CP2004_j + \gamma_{013}\,CP2005_j + \gamma_{014}\,CP2006_j + \upsilon_{0j} \quad (2)$$

$$\beta_{1j} = \gamma_{10} + \upsilon_{1j} \quad (3)$$

$$\beta_{2j} = \gamma_{20} + \upsilon_{2j} \quad (4)$$

$$\beta_{3j} = \gamma_{30} + \upsilon_{3j} \quad (5)$$

$$\beta_{4j} = \gamma_{40} + \upsilon_{4j} \quad (6)$$

where:

$Gender_j$ = male or female for coach $_j$,
$Primary_j$=the dummy variable for primary school coach $_j$
$Junior_j$ = the dummy variable for junior school coach $_j$
$Senior_j$=the dummy variable for primary school coach $_j$
$CP1997_j \sim CP2006_j$ = coach-player ratio of the teams instructed by the coach $_j$ in academic years 1997-2006
$\upsilon_{0j}, \upsilon_{1j}, \upsilon_{2j}, \upsilon_{3j}, \upsilon_{4j}$ = stochastic error term which are assumed to be normally distributed.

Equations (2), (3), (4), (5) and (6), referred to as the 'level two model', are designed to capture variations at the coach level. By modeling the coefficients β_{0j}, β_{1j}, β_{2j}, β_{3j} andβ_{4j} as shown above, total variation in 30-m archery game scores can be divided into that variation which occurs at level one (player attributes) and the variation which occurs at level two (coach attributes). While other methods, such as a one-level dummy variable approach, may provide a similar analysis, they may be less efficient as they consume a greater number of degrees of freedom.

B. Objects and Data Description

In this paper we are able to collect archery competitions data on 2270 players and 146 coaches for the years 1997 through 2007 in Taiwan (i.e. academic years 1997-2006 of Taiwan). The kinds of archery competition game in each year included President Cup, Youth Cup, and Master Cup, all of which are national events held annually. However, in the player-level, the independent variables were gender, education background, years of seniority, and times of participation in games of players; in the coach-level, the independent variables were gender, the coach-instructed school level and the coach-player ratio of coach-instructed team in each academic year. Finally, the dependent variable was 30-m archery game scores in HLM model.

III. Result

First of all, Intra-class correlation coefficients, ICC(1), were calculated to examine between-group variance. The ICC(1) for 30-m archery game scores (30-m AGS) was .30, ($F(144) = 12.86$, $p< .001$), indicating that 30% of the variability in player ratings of 30-m AGS was related to coach membership. However, ICC(1) values were higher than a median value of .12 in the organizational literature [12] and represent moderate to moderately high ICC(1) values [13].

Moreover, we ran null models to examine whether there was systematic between-group variance in the dependent variables. Significant chi squares for 30-m AGS, ($\chi2(144) = 1423.36$, $p< .001$), indicated that this prerequisite was met for each variable. About 30% of the variance in 30-m AGS was between-group variance.

TABLE I. HLM Summary

Variable	Parameter estimate	SE	df	T
Random coefficient regression model				
Intercept γ_{00}	217.26	7.68	144	26.68*
Gender γ_{10}	6.41	1.45	144	4.41*
Education γ_{20}	15.42	2.36	144	6.52*
Seniority γ_{30}	-1.46	0.83	144	-1.77
Times γ_{40}	6.67	0.67	144	9.89*
Intercepts-as-outcomes model				
Gender γ_{01}	-1.46	2.94	139	-0.49
Primary γ_{02}	1.33	5.30	139	0.25
Junior γ_{03}	23.95	4.61	139	5.19*
Senior γ_{04}	14.04	4.48	139	3.13*
CP1997 γ_{05}	1.87	4.17	139	0.45
CP1998 γ_{06}	6.85	4.69	139	1.46
CP1999 γ_{07}	2.13	4.04	139	0.53
CP2000 γ_{08}	0.28	5.38	139	0.05
CP2001 γ_{09}	6.34	5.75	139	1.10
CP2002 γ_{010}	2.32	4.20	139	0.55
CP2003 γ_{011}	-2.85	5.24	139	-0.55
CP2004 γ_{012}	-4.15	5.73	139	-0.72
CP2005 γ_{013}	-9.34	5.05	139	-1.85
CP2006 γ_{014}	24.52	7.87	139	3.12*

The effects of player gender, education, seniority, and times on dependent variables were controlled prior to hypotheses testing. Random coefficients regression models were run to estimate whether player gender, education, seniority, and times were associated with the outcomes of interest. As shown in Table I, the results indicated the player gender ($\gamma_{10} = 6.41$, $t(144) = 4.41$, $p< .05$), education ($\gamma_{20} = 15.42$, $t(144) = 6.52$, $p< .05$), and times ($\gamma_{40} = 6.67$, $t(144) = 9.89$, $p< .05$) significantly effect on 30-m archery game scores while the seniority doesn't ($\gamma_{30} = -1.46$, $t(144) = -1.77$, $p> .05$). Chi-square tests provided evidence that systematic variance in the intercepts across coaches was found for 30-m archery game scores ($\chi_2(144) = 1287.31$, $p< .001$). The significant between-coaches variance in the player-level intercepts of the random coefficient regression models allowed us to use intercepts-as-outcomes models.

A sequence of intercepts-as-outcomes models was performed to test for the hypothesized relationships. Parameter estimates of Level 2 intercepts-as-outcomes models are reported in Table I. The results revealed that the junior, senior, and CP2006 have significant impact on 30-m archery game scores while the coach gender, primary, and CP1997~CP2005 don't have the effect.

IV. Conclusion and Suggestion

A. Conclusion

Results of the above analysis indicate that it is not only conceptually meaningful but also statistically supports the categorization of factors influencing archery game players' scores into coach-level factor and player-level factor. In terms of the scores of archery game players in Taiwan between academic years 1997-2006, different coaches have statistical meaning to the performances of players, accounting for 30% of variance in scores. The remaining 70% of variance is the very factor that comes from players themselves.

This paper further demonstrates that factors —gender, education, and times— urge players to have influence on variance in scores. Among them, the parameter estimate of gender is positive, indicating that male archers had significantly better performance than female players did because male archers could draw a bow better with their more physically-advantaged strengths and shoot an arrow at a quicker speed, making the flying arrow be less affected by external force (such as wind force). Hence, male archers have higher shooting average. The parameter estimate of education is positive, indicating that: higher education background of playing archers means higher scores. With higher education background and resultant higher mental and physical maturity, players may improve their sports performance. The parameter estimate of times is positive, showing that more times of participation lead to higher scores, which may be due to an increase in playing experiences. The effect of seniority is not significant probably because that the variance that the seniority could measure is almost measured by players' education background and times. With "education" and "times" taken into consideration, the statistical model in this paper suggests that the seniority has no statistical significance.

The statistical analysis of coach-level variables sees a more interesting result. The gender of the coach did not influence game scores, demonstrating equally effective teaching performances between male coaches and female coaches. The conclusion is intuitive. Out of curiosity about the influence of coaches in different school levels on players' scores, this paper takes the university coach as the reference, and includes the primary school, junior high school and senior school coaches as three dummy variables (primary, junior, senior) in the statistical model (Note: A player delivers a better performance in a school of different level, while the coach does not. So the values of the variable of players' education background can be set as ordinal variable 1-4, with the coach-level variables set as dummy variable). Results of the analysis show that the primary variable is insignificant, but junior and senior variables are significant and the parameter estimates of junior and senior are both positive. It indicates that the influence of junior high school coach and senior high school coach on archer's scores is superior to that of university coach. In addition, the parameter estimate of junior (=23.95) is greater than the parameter estimate of senior (=14.04), showing that the influence of junior high school coach on archer's scores is superior to that of senior high school coach. As for the insignificance of primary, it cannot be used to conclude that primary school coach is inferior because a number of micro variables concerning the coach and the player are still not separated out, leaving no statistical result that supports the primary school coach. We can assume that this is also because that sports performance is not highly demanded in primary schools, where the trainees are supposed to only develop an interest in archery. Therefore, the statistical model here does not reveal how a primary school coach could actually affect a player's scoring results.

TABLE II. SUMMARY OF FACTOR EFFECT

Level	Factor	Effect	Explanation/Possible reason to not sig.
Player Level	Gender	positive	physically-advantaged strengths
	Education	positive	age, physical, mental maturity
	Seniority	not sig.	we have already considered the "experience" variable
	Times	positive	experience
Coach Level	Gender	not sig.	no difference in coaching performance
	Primary	not sig.	no difference in coaching performance or data problem?
	Junior	positive	better than university coach
	Senior	positive	better than university coach
	CP2006	positive	more quality lead to better performance
	CP1997 ~CP2005	not sig.	no influence on performance or data problem?

Some may argue that the coach of a school of different levels have different influence on the player's score because of the difference in software/hardware resources rather than the coach's individual factors. It is generally believed that the school's resources (hardware, software, etc.) deal much with the quality of training, which plays a vital role in a player's scoring performances. Due to the cost constraint, this paper fails to initiate investigation into the software/hardware resources owned by each school. Instead, this paper organizes the data on coach-player ratio (=1/number of players) of the team instructed by each coach in each academic year, which may be used as a quality index to reflect the software/hardware resources owned by each school. When the data on coach-player ratios of the ten academic years were included in the statistical model, it reveals that only CP2006 is significant, with all other CP values insignificant, as shown in Table I. This paper analyzes the reason and concludes that the few number of archery coaches before 2005 accounts for the fierce competitiveness over studying at those few schools with archery teams. This led to few samples of coach-player ratio and low variance, meaning statistical insignificance. Since 2004 when Taiwan won one silver medal and one copper medal in Athens Olympic Games, the government jumped on the bandwagon by investing more resources in schools of difference levels to establish more archery teams. This is why CP2006 is significant because the sample size of coach-player ratio and variance are included for year 2005 and later years. Positive parameter estimate of CP2006 represents that the greater the coach-player ratio, the higher the player's scores. This result supports that coaching quality affects the player's score, as perceived by the public.

B. Suggestion

It can be inferred from the above model that the factors of both coach and player have statistical significance on the scores. For players, their playing experiences, mental and physical maturity, all of which contributed to their focus on practices over long periods of time, may account for that significance. Therefore, we consider it strategically important to create a well-established competitive sports platform, where players are willing to train themselves as long-term investments.

As for the factor of coach, the data on junior high school coaches, senior high school coaches and university coaches (except for primary school coach) seems to support the argument "coaches at basic levels have greater influence on the player's scores." The competent authorities are to take into consideration the importance of coaches at basic levels for players. The government is advised to invest more resources in basic training of students at junior high schools (or at a lower level). The goal is to lay a sturdy foundation for long-term development of competitive sports.

Although a further verification is required to analyze the effect of coach-player ratio, so far we can conclude that: The quality that coach-player ratio stands for may be an important factor, too, that influences the player's scores. This reminds competent authorities of the importance of investment in software/hardware resources and implementation in order to have better competitive sports performance.

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Kai-Li Wang works as an assistant professor in Graduate Institute of International Sport Affairs, National Taiwan Sport University. His area of interest is the law issue and public policy in leisure. entertainment and sport field. Recently, he did many researches about the image right, patent, public policy and legislation regarding the sport industry based on the approach of economics of law.

Yun-Ci Ye works as an assistant professor in Department of Somatic and Sports Leisure Industry, National Taitung University. His area of interest is sport management, sport consumer behavior, statistics, etc.. Recently, he did many researches about life satisfaction, buying behavior, experience marking based on the mothed of psychology statistics.