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GOLF SWING MOTION ANALYSIS: AN EXPERIMENT ON THE USE OF VERBAL ANALYSIS IN STATISTICAL REASONING

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Abstract. The complexity of human body demands statistical reasoning to perform an analysis of the golf swing. Such reasoning depends on the use of the Informational Data Set, composed of the related objective knowledge, empirical findings, and observational data. Since the image can be described only verbally and the Informational Data Set requires verbal handling the analysis is performed by constructing a verbal model of the swing motion. The analysis reveals two prototypes of swing motion that can produce an image of actual swing motion. It also produces structural explanations of some of the findings by Ben Hogan. The cusp appearing in the locus of the grip is pointed out as the key to the successful realization of the golf swing. It is tacitly assumed that the golfer is right-handed. The possibility of drastic expansion of the realm of statistics by the use of verbal modeling is pointed out.

Key words and phrases: Verbal modeling, Informational Data Set, golf swing, statistical reasoning.

1. Introduction

> "There is no movement in the golf swing so difficult that it cannot be made even more difficult by careful study and diligent practice" (Beard (1993))

The advancement of the study of an object under the lack of sufficient information is the subject of statistical reasoning. The use of stochastic structure to model the state of knowledge about an object is the common method of statistical reasoning and the success depends critically on the choice of the model.

For the construction of a model attention has to be directed to the collection of knowledge related to the subject of investigation. An explicit definition of such collection is given by the Informational Data Set (IDS) composed of the objective knowledge, empirical findings, and observational data (Akaike (1997)).

In the present paper, the historical use of stochastic structures in statistics is reviewed briefly to clarify its relation to the process of acquisition of useful knowledge. The golf swing motion analysis is taken up to illustrate the process of constructing a model by verbal analysis of the object under investigation with the aid of a properly chosen IDS. The analysis is statistical not so much due to the stochastic variability of the motion but by the uncertainty of the knowledge of the structure of the motion.

The characteristic aspects of the golf swing analysis are discussed and the actual process of the analysis is briefly described. The most successful result is the identification

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of two prototypes of the golf swing motion. The final image of the swing motion is obtained by a proper combination of these two motions. The analysis also provides objective explanations of some of the findings by the legendary golfer Ben Hogan. The existence of the cusp in the locus of the grip is noticed and its function is explained as the key to the realization of effective golf swing.

The experience of the present analysis provides some suggestions for the strategy of efficient realization of statistical reasoning in general. Finally, the possibility of drastic expansion of the realm of statistics by the systematic application of verbal modeling is pointed out.

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2. Use of stochastic structures in statistical reasoning

Statistics started as the description of the state of a nation to help the decision by the leader on economic and political planning. Common method of making a decision under uncertainty is to use a randomizer. Classical example is the divination by tortoiseshell in the ancient China, realized by reading the appearance of cracks in the burned shells. The more refined method is by the reading of the random array of yarrow stalks in the form of a Hexagram composed of six yin(- -) yang(—) lines which was adopted in the I-Ching (the Book of Changes).

The teaching of the I-Ching demands careful consideration of the problem before consulting the randomizer (Takada and Goto (1969)). It is even said that a person who knows the I-Ching well does not consult the randomizer. This suggests the minimization of the dependence as the principle for efficient use of a randomizer.

From this point of view conventional method of statistics may be viewed as the method of construction and adjustment of a randomizer by using observational data. The method of least squares is an embodiment of the above principle of minimization of dependence on the randomizer. More generally, it is seen that statistical reasoning in general is concerned with the construction of a model or image, or more generally a hypothesis, for the handling of uncertainties related to a given problem. To emphasize the characteristic of this type of reasoning, it is called constructive statistical reasoning.

3. Use of Informational Data Set

Constructive statistical reasoning is realized through proper use of Informational Data Set (IDS) defined by

$$\text{IDS} = (\text{ID}_1, \text{ID}_2, \text{ID}_3), \tag{3.1}$$

where ID_1 = factual knowledge, ID_2 = hypothetical knowledge, ID_3 = observations, related to the subject of the reasoning. The factual knowledge represents objectively confirmed knowledge and the hypothetical knowledge represents subjective or personal knowledge not yet objectively confirmed, including empirical findings, tentative models, and other results of investigation related to the reasoning (Akaike (1997)). In the following discussions a sentence related to the i-th component of IDS=$(\text{ID}_1, \text{ID}_2, \text{ID}_3)$ is sometimes marked by (ID_i).

Common use of IDS in the field of scientific research is illustrated by the following two examples. In the discussion of the investment model for asset and liability management by Yakoubov *et al.* (1999), it is pointed out that 1) economic theory, 2) investment practice, and 3) historic data, are the three fundamental inputs to the design of the stochastic model. In a standard reference book, the Gray's Anatomy, it is noted that a rapid accumulation is seen with 1) theory, 2) experimental results, and 3) a body of more objective observations, in relation to the science of kinesiology (Warwick and Williams (1973), p. 400). The structure of IDS is usually interdisciplinary and proper use of language is required for its effective handling.

Statistical reasoning is performed by focusing on some particular aspect of the object, ignoring unnecessary details. Verbal expressions are used to describe particular aspects of the subject by using some general concepts. Thus verbal expressions are essentially statistical in the sense that they ignore some of the particularities of the subject. In this sense, verbal analysis is essentially a type of statistical analysis.

The usual difficulty with the verbal analysis is the unavoidable ambiguity. The reduction of the ambiguity demands the increase of complexity or decrease of simplicity of the linguistic expression. The principle of parsimony in the choice of models in statistics, embodied in the use of the minimum AIC procedure, is valid here and the decision must be made to strike a balance between the simplicity and ambiguity.

4. Statistical nature of the golf swing motion

The motion of a human body is related to the three anatomical aspects; skeletal, muscular and neural. The following examples of the IDS and model respectively reflect the concern with these aspects:

IDS(1) = (literature on swing technique, empirical findings, observations):
Model(1) = (stick figure, approximating the motion of skeleton for graphical or numerical analysis),

IDS(2) = (literature on swing technique and anatomy, empirical findings, observations):
Model(2) = (skeleton covered with muscles, for the understanding of movements),

IDS(3) = (literature on swing technique and anatomy, increased empirical findings, observations):
Model(3) = (image of the swing motion, for the control of the motion).

The stick figure of Model(1) is a skeletal representation of human body by the sticks connecting the joints. It is a typical choice for the conventional parametric model fitting to the observation of the motion. An extremely simplified example is given in Jorgensen (1994). The model lacks description of the muscular structure and cannot provide direct guidance for the golf swing motion.

Model(2) takes muscular structure into consideration. However, it is suggested in the Gray's Anatomy that only dominant characteristics of the movement should be pursued, since the structure of movement is extremely complex. This necessitates the adoption of statistical view.

Model(3) takes the role of the brain into account. The golfer needs an image to activate necessary actions of the muscles. This is concerned with the action of prediction and control, the basic functions performed by the brain for the handling of uncertainties.

These examples show that the intention of the analyst specifies the choice of the IDS and that the choice of the IDS specifies the structure of the model.

One serious difficulty with the analysis of the golf swing is that the input that drives the system is not directly observable. The original input to the system is the image of the motion and the description of the image or control signal is given by language. Thus the use of the modeling by verbal representation, or verbal modeling, is mandatory for the golf swing motion analysis.

If the golfer is viewed as a system driven by the reaction from the ground, the input to the system is observable through the measurement of the action of golfer's feet on the ground. An example is given in Carlsoo (1967), where the records of the activities of related muscles are also presented. Conventional method of model fitting may find some application here, as in the case of the analysis of movements on a pedalo by Haken (1996).

5. Initial simple image of the swing motion

The final objective of the golf swing analysis is the stable realization of "far and sure" shots. One simple requirement for the sureness is to "swing the shoulders parallel to the target line". This idea lead to a successful image of the "shoulder switch swing" (Akaike (1999)). The "shoulder switch" is assumed to represent the function of the shoulders that produces the change of the direction of swing motion. The image of the "shoulder switch swing" is an output of the serendipity gained through the search for stable swing motion for about four years. It suggested the necessity of careful analysis of the content of IDS and produced following observations.

The parts of the body with maximum variability of the motion are the shoulder joints. These are ball and socket (spheroidal) joints that allow motions with high degrees of freedom. Rotator cuff, the group of muscles located around the scapula or shoulder blade, realizes an automatic stabilization of the motion of the upper arm to guard the shoulder joint against possible dislocation. Active use of these muscles in the golf swing is confirmed by Jobe and Moynes (1986) (ID_2).

However, the role of the shoulder girdle, the skeletal and muscular structure of the shoulder, is secondary in the swing motion. The latissimus dorsi muscle, the big muscle originating from the lower back and going through the lower part of the shoulder blade to the front of upper arm, act as the prime mover of the arm (Thompson and Floyd (1998))(ID_1).

The latissimus dorsi muscle has a particular structure. The layers of the muscle are spiralizing, in the sense that the layers originating in the lower and upper part of the back are respectively connected to the upper and lower point of the attachment to the front of the upper arm (Warwick and Williams (1973)) (ID_1). Based on the understanding of this structure an image of the swing motion was obtained, but the difficulty still remained with the stable realization of back swing motion.

6. Drastic change of strategy

The original strategy was to find out the functions of the body useful for the golf swing from the knowledges in the IDS. However, the complexity of the functions of muscles is quite tremendous, as is shown in the following quotation:

> "Whether the muscle lengthens, shortens, or maintains its length, and what tension changes ensue depend upon many factors. These include the initial length of the muscle, the proportion of active motor units, or rate of change of this proportion, and the sum of the various forces both extrinsic and intrinsic to which the muscle is subjected, partly through its attachments." (Warwick and Williams (1973), p. 493).

The quotation is followed by the statement that such a mechanism allows an infinite variety of possible quantitative responses of any particular muscle (ID_1).

The probability of reaching a useful swing image by the process of constructing models based on the anatomical knowledge of the muscles is almost reduced to zero by this observation. The remaining strategy is to impose utmost constraint on some already available highly variable motion to see if useful functions are available with less ambiguities. This is an adaptation of the principle of minimizing the dependence on the randomizer discussed in Section 2 and will be called more directly the principle of maximum constraint.

7. Systematic approach to the golf swing analysis

The model or image of the swing motion must be described by some set of concepts that are interpretable by the golfer and realizable in terms of the functions of his body. Thus the analysis is simultaneously concerned with the identification of available functions of the body and with the synthesis of a model or image by the combination of the components defined by the identified functions. The identification can be realized by the application of the principle of maximum constraint, while the synthesis requires detailed analysis of the interaction between the components.

The difficulty with the use of the knowledge of a particular muscle suggests the necessity of adopting a statistical approach where the attention is focused on the characteristic movements generated by some groups of muscles. In the swing motion the basic component is the swing motion of upper arms. The structures of the motions of the forearms, wrists, and hands, are too complex to be discussed here but a proper control can be realized by adjusting the response of the grip to the motion of the upper arms.

The motion of upper arms is controlled either by the group of muscles that bypass the shoulder blades, to be denoted by the group L which is represented by latissimus dorsi muscles that are the prime movers of the upper arms, or by the group of muscles connected to the shoulder blades, the group S. The main components of the group L, the latissimus dorsi muscles, are equipped with the proprioceptors, sensors that assist the balancing of the body along with the eyesight and the sense of the inner ears (Sacks, 1985). The action of the group S will sometimes be described simply as the action of shoulder blades. Rotator cuffs are included in this group. Their active participation in the golf swing motion was already confirmed.

8. Identification of the L and R-swing

The application of the principle of maximum constraint on the movements related to the actions of the muscles of the groups L and S leads to the following identification of the two types of swing motion.

The L-swing: this is the lateral swing motion of the arms realized by placing maximum constraint on the motion of the shoulder blades. The arms are tightly extended with the pronation or inward rotation of the upper arms and the club is kept firmly by the grip with sufficiently abducted wrists. The swing motion is realized by the muscles of the group L, supported by the action of the whole body, including the legs and hips. Golfer's head is kept still by minimizing the rotary motion of the body.

With the "shoulder switch" action, which is the unavoidable action of the shoulder blades at the beginning of the back or forward swing motion, the club head goes outside of the target line in these motions. The club face is turned downwards and upwards in the back and forward swing, respectively, while it is kept square to the locus of the swing motion. This produces outside-to-out motion where the club head approaches the ball from outside the target line and then goes out. This is a type of motion which has rarely been discussed in the literature of golf. The ball hit by this swing motion goes straightly to the right or outside of the target line. This swing specifies a powerful swing motion by the whole body with minimum action of the shoulder blades.

The R-swing: this is a rotary swing motion around the body realized with the swing of the arms by the muscles of the group S while the main part of the body is kept still. This motion is realized with the lateral swing motion of the shoulder blades. If the movement of the shoulder blades is sufficiently active this swing motion generates supination or outward rotation of forearms. With proper adjustment of the grip this motion produces a planer motion of the club in front of the body which draws a semicircular locus of the club head with the club face kept square. This is an inside-to-in motion and is quite effective in generating the head speed. If it is applied to an actual hitting it produces a curved shot to the left.

Actual swing motion is realized by the combination of the L and R-swing motion. Since the amount of the motion of the shoulder blades is kept minimum in the L-swing, the R-swing motion can effectively be added to the L-swing motion at the top and at the impact. Detailed analysis of the structure of this combination provides a crucial observation which is to be discussed separately in the next section.

The structure of the full swing motion can simply be described as follows: 1) the back swing is realized by the L-swing with additional R-swing motion to reach the top, 2) the down swing is started with the L-swing motion, and 3) the "shoulder switch" action of the L-swing excites the forward R-swing motion and realizes an effective motion of the club to hit the ball.

The L and R-swing are the two prototypes of the swing motion. The swing motion obtained by the combination of these prototypes will symbolically be called the Lateral and Rotary swing, or the LR-swing. It may be more suggestive to denote it as the LR-swing by the muscles of the groups L and S, or the $LRLS$-swing. The grip to keep the club face square to the swing locus is a primary requirement for the realization of this swing motion.

With the understanding of the structure of the swing motion the motion is realized by simply following the earlier image of "swinging the shoulders parallel to the target line".

9. Discussion

The outside-to-out motion of the clubhead in the L-swing looks like a mirror image of the inside-to-in motion in the R-swing and provides a visual image for the realization of straight shots by the combination of the two swings. However, there are much more detailed aspects in the action of hitting.

The book by Hogan (1957) "Five Lessons" is notable for its detailed description of the technical details of the golf swing. It is full of observations which should be included in ID_2. In the book the necessity of the strong adhesion between the chest and upper arms is stressed and the importance of the supination or external rotation of the left wrist at the moment of impact is extensively discussed, stating that "Every good golfer has his left wrist in this supinating position at impact." (Hogan (1957)) (ID_2). The present analysis provides structural explanations of these observations.

The strong adhesion between the chest and upper arms is realized by the pronation of the upper arms produced by the contraction of the latissimus dorsi muscles and the antagonistic supination of the forearms by the action of the shoulder blades. This is a defining element of the L-swing which realizes the tight extension of the arms to form the basis for the stable swing motion.

The supinating motion of the left wrist is related to the more delicate hitting motion at impact. With the contraction of the latissimus dorsi muscles driven by the "shoulder switch" the upper arms show strong pronation. This is an antagonistic action to the supination of the arms by the R-swing motion and provides a condition for its powerful realization. This explains the background of the supination of the left wrist observed by Hogan. It also explains the structure and importance of the supination of the right wrist at impact. It can also be seen that the addition of the R-swing motion at the top provides a preparatory motion for effective contraction of the latissimus dorsi muscles in the down swing.

The cusp of the L-swing motion

There is one aspect of the L-swing that deserves to particular attention. This is crucial motion for the effective realization of the golf swing and is related to the action of the "shoulder switch" that specifies the direction of the swing motion. The hitherto rarely discussed outside-to-out motion of the L-swing shows a cusp in the locus of the grip at a slightly advanced position of the ball. The cusp is generated by the strong action of the latissimus dorsi muscles that pulls the grip towards the body to effectively realize the impact. That action is assisted by the action of the shoulders, or the "shoulder switch" action. The existence of the cusp can be confirmed by stroboscopic photographs of golfer's swing motion; see, for example Dante and Elliot (1962)).

With the preparatory extension of the latissimus dorsi muscles by the backward L-swing the cusp is powerfully realized and enables effective combination of the forward motions of the L and R-swing. This realizes the most effective use of the structure of the arms to bring the club head to the hitting position and hit throught the ball. Obviously the performance of a club is highly dependent on its response to this action.

Above observations illustrate some of the complexities and nonlinearities of the functions of human body. It explains how the mutual dependence between the parts of the body and between the muscles makes the construction of the swing image difficult. When the prime mover is pronating the arm the antagonists are producing supinating

action. The pronation of the upper arm is counteracted by the supination of the forearm. The feel of the motion changes depending on the way of focusing the attention by the golfer. In this sense, the adoption of the statistical definition of the L and R-swing by the typical motions of the related groups of muscles was quite successful. The psychological uncertainty disappeared as the definitions of these motions produced simple and almost uniquely interpretable images.

By adopting the concept of the LR-swing one fellow golfer experienced recently the improvement of the rate of getting on the green in regulation figure from 0.30 to 0.46. Another high-handicapper drastically improved the stability of his swing motion by assimilating the concept of the LR-swing, particularly of the supination of the arms associated with the R-swing. These and other similar examples and the result of experiments by the present author confirm the practical utility of the golf swing analysis by the present approach.

It may be of some interest to note that the "turn of the body" which is often discussed by skilled golfers is not touched here. If the body is "turned" forward in the down swing the head of the golfer will turn forward and the right and left shoulder advances and retreats, respectively, from the original relative positions at address. Obviously this drastically reduces the probability of good shot. This seems to be a common cause of trouble for amateur golfers. The center of gravity of the body is located in front of the middle of the lumbar, or the third lumbar vertebra (L3), and significant part of the origin of the muscles of latissimus dorsi is distributed along the back of the lumbar. Since it is already noticed that the latissimus dorsi muscles are equipped with the proprioceptor sensing the balance of the body it seems sensible to consider this position of L3 as the "center" of the swing motion. Contrary to the notion of the "turn", the motion of the upper body is realized to keep this "center" stable with the counteractive action of the lower body which is supported by the reaction of the ground.

Once the basic structure of the LR-swing is verbally identified there is a hope for mathematical formulation or mechanical realization of the swing motion. This suggests the possibility of developing a new swing machine that is useful for the evaluation of golf clubs. This is an interesting subject for further study.

10. General principles of efficient reasoning

Some suggestions for effective realization of statistical reasoning are summarized here. The experience of the golf swing analysis confirms the validity of these suggestions.

1) Attention should be focused on the point with maximum ambiguity or uncertainty: in the case of the swing analysis the shoulder joints showed maximum degree of freedom and the attention was focused on the movements of the shoulders and arms.
2) Pay attention to the dominant structure: the attention in the swing analysis was concentrated on the function of the latissimus dorsi muscles, the prime movers of the arms.
3) The description of actual use of a concept is more informative than the enumerating description of its content: the function of a muscle is often better explained by a typical motion than by the enumeration of the details of the structure.
4) Intention of the observer must be specified to read the meaning of observational data: in the sequence of photos of the golf swing the hips lead the motion of the arms, while intended motion of the arms specifies the action of the hips in an actual

swing.

5) Try the reversal of ordinary view: in the world of golf there is a saying that the reversal of every natural instinct will lead to an almost perfect swing (Hogan (1948)).
6) Avoid the discussion of local aspect disconnected from the whole of the object: it is usual that a dramatic success obtained one day by a local adjustment of the swing motion disappears the next day.
7) The simpler the better: a golfer cannot follow complex image of motion (Nicklaus (1974)). (The principle of parsimonious modeling.)
8) Never stop the search for better understanding: there is no end in the search for better golf swing.

Statistical reasoning endlessly develops through the process of proposing a hypothesis and confirming its validity by referring to the reality.

11. Concluding remarks

It was observed that the essential role of the stochastic structure in handling an uncertainty is to force an utmost use of available knowledge. This clarified the meaning of the use of stochastic models and lead to the discussion of the use of IDS for the construction of statistical models. The handling of IDS forced the adoption of verbal analysis.

The golf swing motion analysis provided an example of practical use of statistical reasoning. The reasoning produced objective explanations of the findings by Ben Hogan and also lead to the important discovery of the cusp in the locus of the grip. This shows the potential of statistical reasoning by verbal modeling in wide areas of scientific research related to the human feeling.

It is hoped that the present paper will encourage the discussion of statistical reasoning as the science of the method of extraction of useful information by proper use of related Informational Data Set. This will almost endlessly widen the area of the research of statistics.

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