EVALUATING PERFORMANCE MEASURES FOR THE BOBSLEIGH PUSH START

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Quantification of performance is essential to understand performance determinants. Therefore, the purpose of this study was to evaluate different performance measures applied to the bobsleigh push start and to discuss the choice of an appropriate measure for research and coaching. Measures based on the change in kinetic energy and based on the change in momentum were calculated for the early acceleration phase during the push start and compared by means of correlation analyses. Both energy-based and momentum-based methods lead to similar results while it is important to consider the athlete and the bob as a system. Further clarification is required on whether the flight phase should be taken into account when calculating performance measures.

KEYWORDS: acceleration, winter sports, skeleton.

INTRODUCTION: The aim of an Olympic bobsleigh competition is to cover a given distance in the shortest time possible. A race can be divided into a push phase and a gliding phase. Since the athletes can only actively accelerate during the push phase, the aim of this phase should be to reach the highest possible velocity before mounting the bobsled. Changes in horizontal velocity when pushing a sled are high in the beginning of the push phase and decrease the closer the athlete gets to maximum velocity (Colyer et al., 2017). Therefore, the ground contacts immediately after the initiation of the push start (1^{st} - 3^{rd} ground contact) are of great importance. Assessing the execution of ground contacts requires a performance measure with high resolution. Measures like overall start time or the velocity when mounting the bobsled might not be accurate enough because they are a result of all prior actions of the athlete. Even though of relevance for understanding performance determinants, no alternative parameter is used in practice or described in biomechanical literature for bobsleigh.
In athletic sprinting, measuring the time to reach a specific distance (Mero et al., 1983) or the velocity at a certain event (Salo et al., 2004) are common practices among coaches and researchers. Due to the same methodological weaknesses as mentioned above, Bezodis et al. (2010) recommended to use normalised average horizontal external power (NAHEP) as a performance measure, originally applied to assess block start performance. NAHEP is based on the change in kinetic energy of the athlete's centre of mass (CoM) divided by time.
When using NAHEP to assess the execution of ground contacts during the bobsleigh push start, this measure could be either calculated for the athlete or the bobsled, or a combination of both. The possible interaction between athlete and bobsled would indicate different outcomes. To which extent these approaches would differ is unclear and therefore its impact on drawing conclusion with respect to performance determinants. Since NAHEP should aim at quantifying the ability to accelerate, its relationship to the average horizontal acceleration (AHA) is assessed. Consequently, the aim of this paper is to compare different performance measures specifically applied to the bobsleigh push start and to finally discuss the choice of an appropriate parameter to be used for future research and coaching.

METHODS: Based on ongoing performance diagnostics with the German national bobsleigh team 100 push starts of 27 athletes were recorded in a laboratory setting on an indoor athletics track equipped with three force plates (1250 Hz, 600 x 900 mm, Kistler Winterthur, CH). Guiding rails were installed to allow for pushing a bobsled along the track. The bobsled

consisted of a custom-made rigid metal frame mounted on 4 wheels. The weights were evenly distributed within the bobsled resulting in a total mass of 85 kg. Retro-reflective markers were firmly attached to reference points on the athletes and the bobsled and their positions in space with respect to time were recorded using 16 infrared cameras (250 Hz, Fx40, Vicon Motion Systems Inc., Oxford, UK). The CoM of the athlete was calculated by inverse kinematics (AnyBody Technology, Aalborg, DK) whereas the position of the bobsled was defined as the midpoint of 4 markers attached to the rigid frame. Both kinetic and kinematic data were digitally filtered by a low-pass 4^{th} order butterworth filter (cutoff frequency: 50 Hz). Ground contacts were detected by applying a threshold of 20 N to the vertical ground reaction force time series. The velocities of the bobsled and the athlete's CoM were derived from kinematic recordings.
In total, 12 different performance measures were calculated (see Table 1). Measures 1-6 are based on NAHEP which is defined as the change in kinetic energy divided by time and further normalised to mass, leg length and the acceleration due to gravity to produce a dimensionless parameter (see Bezodis et al. 2010). Measures 7-12 are based on AHA, which is calculated as the impulse divided by mass and time. All of the measures are applied to the athlete's CoM (A), the bobsled's CoM (B) or the total CoM of both athlete and bobsled combined (C), which is indicated by the respective additional letter. Both kinetic energy changes and changes in momentum were calculated for the duration of the stance phase of the first ground contact (stance) and the duration of the stance and following flight phase (step) of the first ground contact. The latter should account for vertical impulses produced during the stance phase which lead to flight phases during which the athletes cannot accelerate the total CoM of the system.

Table 1: Description of performance measures.

Performance Measure	Description
(1) NAHEPA stance	NAHEP of the athlete during the stance phase
(2) NAHEPB stance	NAHEP of the bobsled during the stance phase
(3) NAHEPC stance	NAHEP of the athlete and the bobsled combined during the stance phase
(4) NAHEPA step	NAHEP of the athlete during the stance and the following flight phase
(5) NAHEPB step	NAHEP of the bobsled during the stance and the following flight phase
(6) NAHEPC step	NAHEP of the athlete and the bobsled during the stance and the following flight phase
(7) AHAA stance	Average horizontal acceleration of the athlete during the stance phase
(8) AHAB stance	Average horizontal acceleration of the bobsled during the stance phase
(9) AHAC stance	Average horizontal acceleration of the athlete and the bobsled during the stance phase
(10) AHAA step	Average horizontal acceleration of the athlete during the stance and the following flight phase
(11) AHAB step	Average horizontal acceleration of the bobsled during the stance and the following flight phase
(12) AHAC step	Average horizontal acceleration of the athlete and bobsled combined during the stance and the following flight phase

Pairwise Pearson correlation coefficients were calculated to assess the dependencies between the performance measures. Furthermore, all trials were ranked based on the different measures and the resulting ranks were compared by Spearman's rank correlation method.

RESULTS: Figure 1 shows the results of the correlation analyses between the different performance measures. All NAHEP and their respective AHA measures were strongly correlated ($r = 0.95$ to 0.98, $p < 0.001$). Athlete's CoM measures were negatively correlated with respective bobsled measures (r = -0.65 to -0.40, $p < 0.001$) and positively correlated with combined measures (r = 0.77 to 0.84, $p < 0.001$). Regarding combined and bobsled measures there was no significant association (r = -0.13 to 0.16, $p > 0.05$). Step vs. stance measures were weakly to moderately correlated with each other for combined and athlete (r = 0.33 to 0.57, $p < 0.05$) parameters and strongly correlated for bobsled parameters (r = 0.97 to 0.99, $p < 0.001$). Ranking the trials based on the different measures resulted in similar correlations but with slightly lower magnitudes.

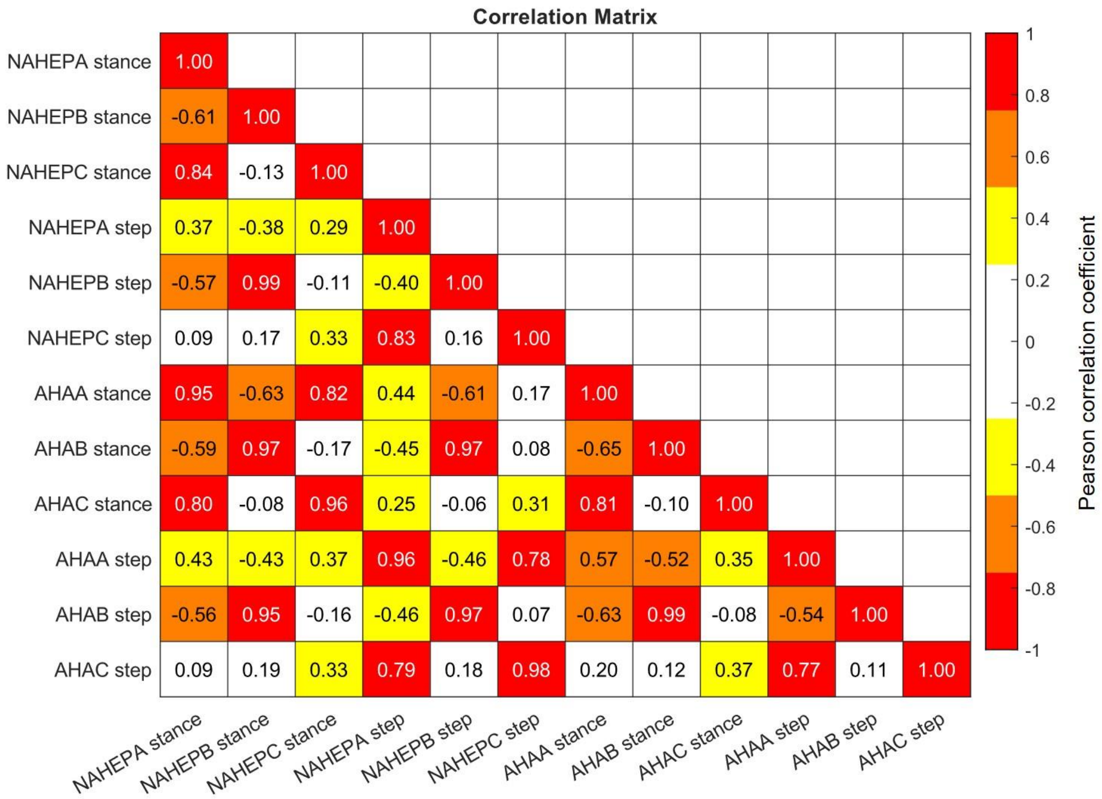

Figure 1: Correlation heatmap of selected performance measures based on respective Pearson correlation coefficients.

DISCUSSION: The aim of this paper was to compare different performance measures applied to the bobsleigh push start and to discuss the choice of the most appropriate measure. The almost linear relationship between the parameters based on NAHEP and the ones based on AHA (see Figure 1) stems from the fact that both measures contain horizontal velocity and time as the only non-constant variables in the formula. Since velocity is squared when calculating NAHEP but not when calculating AHA, the correlation is not expected to be perfect. The strong linear dependency in the context of the bobsleigh push start suggests that it is indifferent which base to use. However, it is noteworthy that ranking the athletes is still sensitive to the choice of parameter. For instance, the highest difference was one athlete being ranked 1st based on NAHEPC step and 6th based on AHAC step. When choosing a performance measure, the differences between measures and their consequences have to be considered. The two main differences between energy-based measures (NAHEP) and impulse-based measures (AHA) are the normalisation and the mathematical treatment of velocity changes in the formulas.

Firstly, normalising to mass seems reasonable because heavier athletes (bobsleds) require more mechanical power to accelerate. Further scaling to leg length was originally introduced by Hof (1996) in the context of gait analysis. While this mathematical procedure might make sense when comparing step lengths for instance, the justification when assessing acceleration might be questionable. In elite sports reaching a high velocity or covering a distance in the shortest time possible is not normalised to leg length and this should be consistent when assessing sub-phases of a sprint or push start.

Secondly, the mathematical treatment of velocity in the respective formulas has an effect on the consideration of the initial velocity. For a specific change in velocity NAHEP will produce greater values for higher initial velocities. It is possible that even for lower accelerations NAHEP will be greater simply because athletes are closer to maximum velocity. On the one hand, this circumstance makes NAHEP more difficult to interpret, on the other hand, it might be more appropriate to consider the initial velocity, especially when the aim is to evaluate several steps during the acceleration phase. Since the ability to further accelerate decreases with increasing velocity, a lower acceleration during the first ground contact will potentially lead to a higher acceleration during the second ground contact, for instance. This dependency is only considered when taking the horizontal velocity at touchdown into account. In cases for which the initial velocity is zero, as for the block start in sprinting or as for the push initiation during bobsleigh this can be neglected.
Regardless of the choice of NAHEP or AHA, the question on whether to apply these measures to the athlete, the bobsled, or both, remains. The negative correlation between CoM and bobsled measures suggests that the velocity changes of athlete and bobsled deviate from each other. Further investigation of the horizontal velocity time series of both bobsled and athlete confirmed this assumption. The horizontal velocity time series of the bobsled show an almost linear increase during the initial acceleration phase of the push start whereas the horizontal velocity of the athlete’s CoM shows distinct phases of deceleration and acceleration. High acceleration of the bobsled is associated with low acceleration of the athlete and vice versa. Due to feasibility reasons – especially in the field – it would be attractive to solely look at the bobsled without having to calculate the CoM of the athlete, but the complex interaction between bobsled and athlete does not support this simplification. Therefore, the change in horizontal velocity for both athlete and bobsled as a system has to be considered.
Lastly, performance measures can be applied to the stance or the stance and the following flight phase (step). Accounting for both stance and flight phase assumes that it is possible to produce different vertical accelerations for a given horizontal acceleration during the stance phase, which is not clear. Dividing by step time would penalize long flight phases during which the athletes are not able to further accelerate. With regards to bobsleigh it is noteworthy that the flight phase is not only affected by the vertical velocity of the athlete at take-off and potential landing and take-off asymmetries but also by the possibility to interact with the bobsled. The correlation between stance and step-based measures were only weak when calculated for the total CoM of both bobsled and athlete which also led to inconsistent rankings of the athletes. The underlying aforementioned assumption for considering step times requires further clarification.

CONCLUSION: NAHEP and AHA are closely related and result in similar rankings of athletes. When assessing the acceleration phase of the bobsleigh push start both athlete and bobsled should be considered as a system.

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