EVALUATION OF THE GRAVITATIONAL CONSTANT USING CONVENTIONAL INSTRUMENTATION

P. Luhtanen, H. Mononen, A. Salo, M. Salonen, J. Viitasalo

Research Institute for Olympic Sports
Jyvaskyla (RIOS), Finland

INTRODUCTION

Standardizing research procedures in sport biomechanics is a difficult task. The data collection process is highly dependent on the instrumentation used, and technological advances. Remarkable changes have occurred in hardware, software and applications. The development of data processing and analysis procedure has changed the whole concept of how we interpret both collected raw data and mathematically derived data.

Kinematic data can be collected with several cinematographic methods, such as filming procedure, single-plate techniques, optoelectric monitoring systems and television-video systems (e.g. Winter, 1979) which include also high speed video systems. Equipment specifications, calibration procedures and expected reliability vary according to each respective system and aimed measurement.

Kinematic parameters as accelerations must be measured accurately if they are going to reflect the true movement history of a particle. Acceleration values derived from the spatial coordinates of the particle are meaningless unless proper techniques have been employed prior to differentiation. The major problems arise from nonsystematic errors found in the raw data. The error component of the kinematic data can result from such things as perspective error, digitization error, digitizer resolution, camera vibration, motion analyzer distortion, synchronization error, calibration error and identification error of the anatomical landmarks.

For further analysis of the data, it is important to consider the role of sampling rate and smoothing techniques of the data for reliable and valid results. The normal calibration procedure for a motion analysis system is to use a test of an object whose displacement history is known. The accuracy of this system is good as long as the measured and reference value remains the same or is on the inside of a low percentage.

The computation of the velocity and acceleration history of a movement by taking the first and second derivatives of the measured displacement data contains many dangers. The inaccuracies in the recording and digitizing process amplifies significantly errors in the results unless the appropriate smoothing steps are taken (Winter, 1979). Currently, two accepted approaches are used to reduce or smooth out the errors that occur in the higher order derivatives. The first approach involves the use of a digital filter followed by a finite difference technique (Pezzack et al., 1977). The second approach involves the fitting of special mathematical functions to the displacement-time curves as Fourier series and spline functions (Soudan and Dierskx, 1979).

This study is part of a large validation project in sports biomechanics at RIOS. The purpose of this study was to validate the gravitational constant in free fall conditions and to find the best combination in the selected shooting, analysis, digitization and smoothing methods.

METHODOLOGY

NAC 400 HVS camera recorder unit at frame frequency of 100 Hz with full frames was used to record drops of a small ball (m=47.0 gm and diameter=23 mm). A 2-D reference frame in the fall plane of a white reflecting ball was used to calibrate the distance scale. A white reflecting ball was dropped from the height of 1.70 m, with a dark gray textile as the background. The optical axis of the camera was directed perpendicularly into the center of the dropping line at a distance of 17.75 m from the camera. The drops (inside of the reference frame) were filmed with a shutter speed 1/2500 s and without the camera shutter. An Ariel Performance Analysis System was used to grab, digitize, smooth and analyze the gravitational constant in the free fall of the ball.

The recordings were digitized in the automatic and manual mode for each full frame. The gravitational constant was calculated using a cubic spline smoothing technique with the coefficients of 1.0 (default value) and 0.3 (user's value). The measurements were repeated in the sets of five drops. An example of the plotted g values in a sample is shown in Figure 1. The ball is released at the point of 0.11 s.

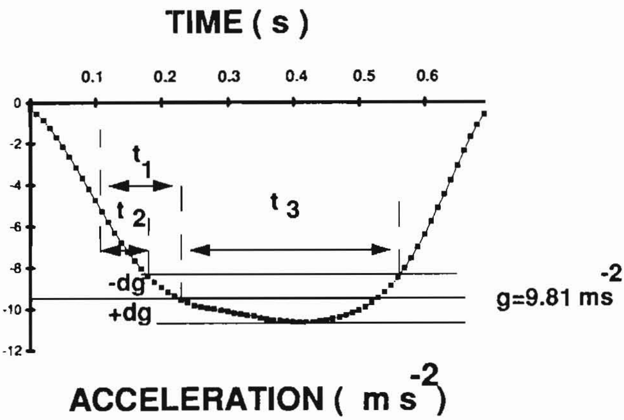

Figure 1. A plotting of the gravitational constant in a trial, with respect to time.

Selected characteristics were observed from the curves as follows:

1. extreme value of the g
2. deviation (±dg) from the correct value of the g (dg= | g max | - g true)
3. delay from the release to the value of g (t1)
4. delay from the release to the value of (g-dg) (t2)
5. average of the g within the deviation of the -dg and +dg (for t3)
6. duration of the g within the deviation of the ±dg from g (t3)

RESULTS and DISCUSSION

The single extreme value of the g varied between 10.24 ms^{-2} and 11.13 ms^{-2}. The single deviation (-dg and +dg) from the correct value of the g was a maximum, 1.23 ms^{-2}. The delay from the release to the value of g (t1) ranged from 0.11 s to 0.18 s. The average g within the time (t3) ranged from 9.87 ms^{-2} to 10.21 ms^{-2}. The duration of the g within the deviation of the -dg and +dg from g (t3) was between 0.19 s and 0.38 s.

A 3-way procedure of ANOVA was applied to the selected characteristics in the g curve in respect of the digitizing method, utilization of the shutter and smoothing method (Table 1). The best average estimation and minimum deviation of g were reached with automatic digitization, shutter, and 1.0 cubic spline smoothing technique.

Table 1. Selected ANOVA statistics concerning the average g and maximal deviation of the g from the expected value.

Source of variation	Average g F	Average g p	Deviation of the g F	Deviation of the g p
Main effects	62.23	0.000	56.85	0.000
Digitizing	0.59	0.448	15.62	0.000
Shutter	17.48	0.000	29.00	0.000
Smoothing	168.90	0.000	125.94	0.000
2-way interactions	5.42	0.004	3.61	0.024
Digitizing Shutter	16.08	0.000	0.12	0.729
Digitizing Smoothing	0.14	0.714	8.15	0.006
Shutter Smoothing	0.04	0.843	2.20	0.148
3-way interactions	1.36	0.252	1.10	0.301
Explained	29.23	0.000	26.07	0.000

The time history of the gravitational constant varied according to the digitization, use of the shutter and smoothing technique. Table 2 presents the ANOVA statistics for the sources of variation in the delay to reach the correct g.

Table 2. Selected statistics of ANOVA concerning the delay of g from the release (t1) and duration of the "constant g" within the deviation of the -dg and +dg from g (t3).

Source of variation	Delay of the g F	Delay of the g p	Duration of the "constant g" F	Duration of the "constant g" p
Main effects	57.40	0.000	666.70	0.000
Digitization	10.03	0.000	8.80	0.006
Shutter	3.88	0.058	35.20	0.000
Smoothing	158.31	0.000	1956.07	0.000
2-way interactions	3.43	0.029	0.92	0.442
Digitization Shutter	10.03	0.003	0.65	0.424
Digitization Smoothing	0.18	0.672	1.82	0.187
Shutter Smoothing	0.07	0.799	0.29	0.593
3-way interactions	0.89	0.353	0.07	0.789
Explained	26.20	0.000	286.13	0.000

The main effects concerning the value of gravitational constant and its timing were significant ($p<0.001$) due to the smoothing technique, use of the shutter and digitization mode. No clear two- or three-way interactions were found.

The individual and average maximal worst g values differed from the correct value by 13.5% and 4.1%, respectively. Statistically significant differences were mainly due to the smoothing technique ($p<0.001$). The role of the shutter for the average g and its deviation was significant ($p<0.001$). The best individual and average gravitational constant were achieved with cubic spline by the coefficient 1.0, shutter and automatic digitization technique. However, the delay to reach the correct g was the longest, and time for the average g was the shortest with the above mentioned recording and analysis combination.

The quickest adaptation in time and duration for the constant g value was reached using cubic spline smoothing with a coefficient of 0.3. The smoothing technique influenced all timing characteristics significantly ($p<0.001$). For the timing characteristics, the role of the use of the shutter and digitization mode was significant ($p<0.058$) in all cases.

In the best evaluation of the gravitational constant the g value should be reached at once and keep it correct and constant as far as the ball was falling. The fastest instantenous correct g value was reached with the cubic spline smoothing by the coefficient of 0.3. The best average g value was reached with the coefficient of 1.0. The maximum deviation from the true g value was due to the manual digitization.

CONCLUSIONS

It can be concluded that the instantaneous acceleration is very sensitive to the methods of recording, digitization and smoothing techniques. According to this study, utilization of the shutter and automatic digitization mode could be recommended. More attention should be focused on the best possible smoothing technique with respect to the object of study. Additional validation processes will be needed for acceleration measurements and standardization of the methods for different measurement problems.

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