Aerial Somersault Performance Under Three Visual Conditions

Jan M. Hondzinski and Warren G. Darling

Experiments were designed to examine the visual contributions to performance of back aerial double somersaults by collegiate acrobats. Somersaults were performed on a trampoline under three visual conditions: (a) NORMAL acuity; (b) REDUCED acuity (subjects wore special contacts that blocked light reflected onto the central retina); and (c) NO VISION. Videotaped skill performances were rated by two NCAA judges and digitized for kinematic analyses. Subjects’ performance scores were similar in NORMAL and REDUCED conditions and lowest in the NO VISION condition. Control of body movement, indicated by time-to-contact, was most variable in the NO VISION condition. Profiles of angular head and neck velocity revealed that when subjects could see, they slowed their heads prior to touchdown in time to process optical flow information and prepare for landing. There was not always enough time to process vision associated with object identification and prepare for touchdown. It was concluded that collegiate acrobats do not need to identify objects for their best back aerial double somersault performance.

Introduction

Although some acrobats deny using vision during skill performance, many report they use and rely on visual information, especially during the pre-landing phase of aerial skill performances. Research has shown that vision plays an important role in landing aerial somersaults. Subjects had fewer steps, hops, and/or falls after landing back (Bardy & Laurent, 1998; Rezette & Amblard, 1985) and front (Lee et al., 1992) aerial somersaults when their visual field was not obscured than when it was blocked. Furthermore, Rezette and Amblard (1985) have suggested that visual motion cues were necessary for good acrobatic performance because subjects experienced better landings when performing the back somersault in normal lighting conditions compared to the sporadic use of optical input during 12 flashes per second stroboscopic lighting. Others have also shown that precision of landing control was improved when subjects could see (Bardy & Laurent, 1998; Lee et al., 1992). Evidence for this better control included more consistent body position as the athletes approached landing and less variability in a time-to-contact variable at touchdown (see Lee et al., 1992, and Bardy & Laurent, 1998, for the variable description).

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Optical, vestibular, and somatosensory input can be used to sense body orientation when airborne. Although interactions exist among these systems, it is the influence of optical input that is of major interest in this study. As mentioned previously, there are discrepancies in accounts of vision use by acrobats. Such discrepancies may arise from the individual's definition of the term vision but are more likely due to the type of optical processing.

Optical information or input has been defined as the light that reflects off objects and onto the retina (Michaels & Carello, 1981). Furthermore, detection of optical information is described as visual perception or vision (1981). There are two types of optical input processing. P-cells that are concentrated in the fovea project through the parvocellular pathway of the lateral geniculate nucleus (LGN) to the inferior temporal cortex. These ventral stream projections process information concerned with form perception and object identification. This is the more common definition for vision and is probably what acrobats were referring to when they described whether they use vision for aerial somersaulting performances. Optical input can also be used to analyze motion and spatial relations of objects in the visual field. M-cells, located throughout the retina, project through the magnocellular pathway of LGN to the posterior parietal cortex (dorsal stream). Projections to these cortical areas do have inter-connections; thus, the ventral and dorsal streams are not completely dichotomous (Pritchard & Alloway, 1999).

Relative movement between an observer and the visual scene causes movement across the viewing field, referred to as optical flow information. This information has been shown to induce feelings of movement and sway in stationary adults (Wood, 1895) and falls in infants (Lee & Aronson, 1974). In these studies, postural sway was induced by motion of a "moveable surround" during stance. Sway corresponding to room movement was initially thought to be controlled primarily by input to the peripheral retina (Lee & Lishman, 1975). Later, it was found that the stimulus was the sensitivity of the peripheral retina to laminar flow (Koenderink & Van Doorn, 1981) and not to radial flow (Stoffregen, 1985) information, suggesting that the retinal location for visual information detection is not the only consideration used for visual control of motion. Nonetheless, optical flow information is also available to acrobatic athletes during somersaulting, but unlike the stationary subjects viewing a moving background, visual, vestibular, and somatosensory information for self-motion are in agreement. Therefore, optical flow input may enhance performance (including improved landings) by verifying the information provided by the other senses, rather than cause imbalance, as when the body is stationary. As mentioned previously, there is evidence to support the conclusion that acrobats utilize optical flow information to help maintain balance on landing (Rezette & Amblard, 1985). This begs the question: Is object identification (visual perception) necessary for the best aerial somersault (SS) performance?

Many coaches have found that acrobatic athletes can improve their performance scores by spotting1 (Kimball, 1962). Reports from the United States Diving

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1Spot may be defined as a verb: to visually fixate on an external reference point during a rotational skill, that may help suppress disorientation and assist in identifying the position and orientation of the athlete's body in flight; or as a noun: the externally viewed reference point (Hogue, 1990). Note: A spotter is a person who provides external assistance during skill performances.
Safety Manual state that divers should be taught to use spotting during their performances (Hogue, 1990). Elite athletes performing back single SSs were shown to slow head rotation twice while airborne, at take-off, and pre-landing (Pozzo et al., 1992). If sufficient head slowing occurs (as reported previously by Pozzo et al., 1992), the acrobat could fixate the eyes on an external target (spot), and gaze could be stabilized. Such gaze stabilization could be used for object identification and will be referred to as object vision in this manuscript. It has been reported anecdotally that it is important for divers to see identifiable objects on all dives to assist the athlete in orienting him/herself during flight (Kimball, 1962). In addition, there are many reports of divers identifying objects while performing aerial rotational skills. It seems clear that gaze stabilization to the point of object recognition can be accomplished during performance of such skills, but it is unknown whether object vision is needed for spotting to be effective in performance of successful dives. In other words, is object vision used to improve skill performance?

To answer the question of whether good acuity for object vision is needed for acrobats to perform their best, we reasoned the following. If optical inputs required for object identification were eliminated while subjects performed aerial SSs, and their performance level was maintained, then such cues must not be necessary for their best performance. Experiments that directly test the use of only object vision or only motion cues during aerial SSs are difficult to achieve because of the overlap between the visual pathways. Cells that project to the parvo- and magno-cellular pathways are found throughout the retina. By blocking light to a subject’s macular region, we thought that we could greatly reduce an athlete’s visual acuity and the projections to the parvocellular visual system. This would decrease the ability of subjects to identify objects and allow us to determine the influence of reduced acuity on subject’s somersaulting performance. Therefore, we studied acrobatic athletes’ aerial somersaulting performance under three visual conditions (normal acuity, reduced acuity, and no vision). If Kimball (1962) was correct in his reports, subjects would perform best in normal vision condition, poorer in reduced vision condition, and poorest in the no vision condition.

We assumed that by eliminating light reflection to the fovea and/or macular regions, projections through the parvocellular system would be reduced to a greater extent than the magnocellular system and possibly give insight to the visual control of aerial SSs. To gain a better understanding of the contribution of vision to body orientation control during aerial SSs, we studied the control of body orientation prior to landing, via an angular temporal variable related to braking.

**Methods**

**Subjects**

Six acrobats from the University of Iowa diving and gymnastics teams gave written consent, which was approved by the Institutional Review Board of the University of Iowa, to participate in these experiments. Data collection was performed in the latter half of, or soon after, the competitive season. Prior to data collection, subjects were screened by an optometrist. Eye test results verified that the subjects were free of eye disease, had normal uncorrected visual acuity, and had adequate
contact lens fit (needed for trials involving the contact lenses—see Tasks). None of the subjects was accustomed to wearing corrective lenses.

Tasks

Subjects were asked to perform back double SSs to the best of their ability under three visual conditions: normal acuity (NORMAL), in which nothing blocked optical input; reduced acuity (REDUCED), where subjects wore special contacts with the central 8 mm opaque to reduce optical input; and NO VISION, in which subjects wore opaque goggles to block optical input. During data collection, subjects wore either a headband (Figure 1) for NORMAL and REDUCED trials or the opaque goggles, which bore two bright markers to simplify digitization of head position for NO VISION trials. Each subject was allowed a stretching warm-up along with several jumps on the trampoline. Each skill was preceded by three full bounces. Subjects 1–3 performed five NORMAL and five NO VISION trials on the 1st day of data collection, and performed five NORMAL and five REDUCED trials on the 2nd day of data collection. Subjects 4–6 performed five NORMAL, five NO VISION, and five REDUCED trials on the same day. Order of NORMAL and NO VISION conditions was randomized, while the REDUCED condition was always performed last because the eyes of the subjects needed to be dilated to prevent hippus, which could vary the amount of light reflected on the retina and, thus, the subject’s acuity during performances. Table 1 indicates the number of trials performed by each subject in each condition. Just prior to data collection in each condition, subjects were also given one practice trial of the appropriate skill.

Prior to performance, subjects were attached to an overhead spotting belt set over the trampoline where data collection occurred. Experienced spotters were told to assist the acrobat only if needed to prevent injury. Subjects were instructed to perform each skill to the best of their ability and were allowed to rest as desired throughout the experiment. After each trial, the spotter reported whether he had assisted the athlete before, at, or after touchdown.

Contacts

Pupils were dilated before placing the contacts on the eyes. Full dilation was achieved in 25 min. Binocular acuity was tested both before and after placement of the contacts on the eyes to provide an accurate measure of decreased acuity under the external lighting conditions in the gymnasium, where data collection occurred. Each subject’s visual acuity was recorded and is presented in Table 2.

A loss of visual acuity from 1.0 (20/20) to 0.3 (20/70), a difference of 0.7, is considered evidence that foveal vision is blocked (Figure 24-2 in Moses & Hart, 1987). The fact that all subject’s acuity reductions (acuity before – acuity after, Table 2) were equal to or greater than 0.7 (rounded) showed that at least their foveal vision (central 0.09 radians) was blocked (Table 2). Evidence also indicated that the opaque center of the contacts prevented light reflection on the central 0.32 radians of the retina in 4 of the 6 subjects and therefore the whole macular region was blocked (acuity reduction > 0.9; Moses & Hart, 1987).

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Hippus is a rhythmic contraction and dilation of the pupil, independent of illumination or fixation changes (O’Toole, 1997).
### Table 1  Subject and Performance Score Summary

<table>
<thead>
<tr>
<th>Subject gender</th>
<th>Age (hours per week of training)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Visual condition</th>
<th>Number of trials</th>
<th>Mean score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-F diver</td>
<td>21 (19)</td>
<td>1.57</td>
<td>57.6</td>
<td>NORMAL</td>
<td>10</td>
<td>7.22 (0.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>5</td>
<td>7.10 (0.16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>6.52 (0.55)</td>
</tr>
<tr>
<td>2-M diver</td>
<td>19 (20)</td>
<td>1.88</td>
<td>78.9</td>
<td>NORMAL</td>
<td>10</td>
<td>7.63 (0.50)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>4</td>
<td>7.48 (0.66)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>6.20 (0.16)</td>
</tr>
<tr>
<td>3-M diver</td>
<td>21 (20)</td>
<td>1.85</td>
<td>76.2</td>
<td>NORMAL</td>
<td>10</td>
<td>7.19 (0.62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>5</td>
<td>7.29 (0.54)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>6.42 (0.72)</td>
</tr>
<tr>
<td>4-M gymnast</td>
<td>22 (18)</td>
<td>1.63</td>
<td>61.2</td>
<td>NORMAL</td>
<td>5</td>
<td>7.63 (0.48)</td>
</tr>
<tr>
<td></td>
<td>15 years experience</td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>5</td>
<td>7.75 (0.25)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>6.38 (0.38)</td>
</tr>
<tr>
<td>5-F gymnast</td>
<td>18 (20)</td>
<td>1.63</td>
<td>58.0</td>
<td>NORMAL</td>
<td>5</td>
<td>7.35 (0.36)</td>
</tr>
<tr>
<td></td>
<td>15 years experience</td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>5</td>
<td>7.20 (0.27)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>6.56 (0.45)</td>
</tr>
<tr>
<td>6-F gymnast</td>
<td>18 (20)</td>
<td>1.55</td>
<td>48.0</td>
<td>NORMAL</td>
<td>5</td>
<td><strong>7.29 (0.79)</strong></td>
</tr>
<tr>
<td></td>
<td>9 years experience</td>
<td></td>
<td></td>
<td>REDUCED</td>
<td>5</td>
<td>6.17 (0.58)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NO VISION</td>
<td>5</td>
<td>7.13 (0.29)</td>
</tr>
</tbody>
</table>

Figure 1 — The six points digitized from the videotape are shown. They include: front and back head markers and shoulder, hip, knee, and ankle joints. Orientation angles relative to vertical for the head and trunk are also shown.
Table 2  Binocular acuity, Before and After Contact Placement, and Identification of the Visual Field Being Blocked

<table>
<thead>
<tr>
<th>Subject</th>
<th>Binocular Acuity Before</th>
<th>After</th>
<th>Visual field blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20/20^1</td>
<td>(0.96)</td>
<td>20/64^2</td>
</tr>
<tr>
<td>2</td>
<td>20/12.6^3</td>
<td>(1.45)</td>
<td>20/100^1</td>
</tr>
<tr>
<td>3</td>
<td>20/20^4</td>
<td>(1.05)</td>
<td>20/160^2</td>
</tr>
<tr>
<td>4</td>
<td>20/16^3</td>
<td>(1.25)</td>
<td>20/160^1</td>
</tr>
<tr>
<td>5</td>
<td>20/16^2</td>
<td>(1.15)</td>
<td>20/64^2</td>
</tr>
<tr>
<td>6</td>
<td>20/12.6^2</td>
<td>(1.45)</td>
<td>20/64^2</td>
</tr>
</tbody>
</table>

Note. A negative superscript shown after an acuity ratio represents the number of letters of the five on that line that the subject identified incorrectly. A positive superscript shown after an acuity ratio represents the number of letters on the next line (for better acuity) that the subject identified correctly. The number in parentheses represents the ratio, corrected by interpolation when appropriate.

Data Collection

Athletes were videotaped at 60 Hz from the side (electrical shutter set at 1/500 s) with a stationary Panasonic S-VHS Reporter camera (model AG-450, Matsushita Electric Industrial, Okayama, Japan) while performing the back aerial double SS tuck. Camera placement was approximately 1 m above the trampoline bed and 12.2 m lateral to the trampoline center. The lens was zoomed to help reduce parallax effects while including the trampoline bed laterally and the subject’s whole body vertically during performances. Skill performance was assumed to be coplanar.

Data Analysis

Scoring. In both diving and gymnastics, points are awarded to the athletes for their performances. Points are awarded for the execution/takeoff, height, form, and entry/landing (Bowers et al., 1972; United States Diving Incorporated, 1998). All videotaped trials were scored for these attributes by an NCAA diving judge and an NCAA gymnastics judge. Both judges knew that visual input was being varied, but one was ignorant to the details (in REDUCED trials). Thus, the order of somersault performances under different visual conditions (as presented to the judges on videotape) was varied.

Dependence of the qualitative judges’ scores on the more quantitative landing scores was also examined. As previously stated, landings are one basis on which to rate acrobatic skills (Bowers et al., 1972; United States Diving Incorporated, 1998). The International Gymnastics Federation code of points (International Gymnastics Federation, 1993) reports guidelines for deductions in regards to landings. Landing scores for the present work were based on this code of points but modified slightly due to the landing surface. Subjects received 0 points for no forward, backward, or lateral movement on landing; 1 for a small (< shoulder
width) hop/step; 2 for a medium (>1 but <2 shoulder widths) hop/step; 3 for a large (>2 shoulder widths) hop/step or two small hops/steps; 4 for any greater number of hops/steps or hand/knee support; and 5 for a fall.

Digitizing. The PEAK System (Performance Technologies, Englewood, CO) was used to digitize six points on the subjects from videotapes for subsequent two-dimensional kinematic analyses (Figure 1). All trials reported in Table 1 were digitized. Two points were located on the headband or goggles, and the other four points included the athlete’s near shoulder, hip, knee, and ankle joints (Figure 1). Both x- and y-values of the digitized points were filtered with a 10-Hz fourth-order lowpass filter and zero phase. This cutoff frequency was selected on the basis of Fast Fourier analysis and viewing of raw and filtered (6–12 Hz cut-off) data for the fastest moving point (head marker).

Computations

Coordinate Transformation. The PEAK coordinate system was transformed into an earth-fixed reference frame. A 2.5-m scaling rod was placed horizontally on the middle of the performance surface before and/or after subject's performance. The rod's position would have been parallel to the subject's mid-sagittal plane if placed during skill performance. The angle (δ) between the line connecting the two endpoints of the rod (digitized on the PEAK system) and the PEAK system horizontal was calculated. This angle and the distance (D) between the two points (in PEAK system coordinates) were used to project all points digitized on the subject into the new "true" or external two-dimensional coordinate system using the following equations:

\[ x = \frac{2.5}{D} \left( P_x \cos(\delta) + P_y \sin(\delta) \right) \]  

\[ y = \frac{2.5}{D} \left( -P_x \sin(\delta) + P_y \cos(\delta) \right) \]

where, x and y represent the 2-D points in the external coordinate system, and \( P_x \) and \( P_y \) are the x- and y-values of the digitized points in the PEAK coordinate system.

Orientation and Velocity

Orientation of body segments was computed as the elevation angle made between the line connecting two digitized points and vertical. The two points used to determine each body segment (head and trunk) can be seen in Figure 1. Angular velocities were determined by five-point differentiation of respective orientation data. Equal weighting of each time segment during the differentiation process was used.

Time-to-Contact Information

A variable representing temporal proximity to the landing surface was also computed to determine if performance in conditions where optical cues were available provided information concerning time-to-contact at landing. Details of this variable can be found elsewhere (Lee, 1976; Lee et al., 1992) but are briefly described
here. Expansion rate of the retinal image of an approaching object is proportional to time-to-contact information, known as tau, and has been defined for linear movement (Lee, 1976). A similar relationship was also suggested for rotational movement (Lee et al., 1992). The authors proposed the precision of angular control during aerial SSs was related to time-to-contact information (temporal proximity) provided to subjects through rate of expansion of the retinal image as the subject approaches the landing surface (Lee et al., 1992). In the present manuscript, a time-to-contact variable calculated from rotational movement, Angtau, was determined by taking the ratio of the angle between the line connecting the hip and ankle relative to vertical to its rate of change. The hip-ankle angle relative to vertical was chosen because it appeared in the videotaped performances that this was the angle the subjects were trying to control by keeping it close to zero (just short of vertical) at touchdown. The hip-ankle relationship is different from the temple-ankle relationship that was previously presented by Lee and colleagues (1992). Their subjects performed forward single aerial SSs, whereas the subjects in the current study performed backward doubles, which may account for the possible differences in control strategy between the two subject groups.

Errors

To estimate digitizing errors, one trial was digitized three times, and intraclass correlation coefficients (ICC) were determined for x- and y-values of the six points digitized throughout the whole trial. High ICCs (ranging from 0.9986–0.9999) verified quantitatively that digitizing variability was very low.

Statistical Analyses

Angular head, trunk, and neck (head – trunk) velocity data were examined to determine if angular head velocity decreased noticeably relative to the trunk and external environment during the pre-landing phase. Head slowing to 1.75 rad/s has been shown previously for back single aerial SSs performed off a trampoline (Pozzo et al., 1992). Minimum head angular velocities prior to 200 ms from touchdown and 100 ms from touchdown were measured to determine whether head slowing was sufficient to permit gaze stabilization during these times.

Quantitative statistical analyses were performed using the SAS (SAS Institute, v. 6.12a) software package. Comparisons of variables among the different visual conditions were made using a repeated measures analysis of covariance (ANCOVA). Independent fixed variables included the visual condition (NORMAL, REDUCED, and NO VISION), whether the subject received external assistance (yes, no), and day of skill performance (DAY, 1st or 2nd) for subjects that performed on 2 separate days. Random independent variables included the subject (1–6), the judge (1 or 2), and the trial number (1–104). Trial number was nested in subject. Performance score was the dependent variable, while external assistance and day were added to the analysis to test for confounding effects.

Interpretations of the main effects in the statistical analyses were based on a significance level of $\alpha < .05$. A least squares means test was used to make comparisons across the various visual conditions. Significance level for the post hoc tests were reduced, using a Bonferroni correction, to $\alpha_{RC} < .05/n$ (Kleinbaum et al., 1988). The adjusted significance level was $\alpha_{RC} = .017$. The power for each of the
findings (between vision groups) was also calculated using the difference between mean performance scores for each subject and the associated standard deviation. Linear regression was used to determine if there was a correlation between the more quantitative measure of landing score and the more qualitative measure of performance score. A separate ANOVA was conducted on the means of the mean and standard deviation (SD) of Angtau determined at touchdown for each subject in each condition. This was to determine whether Angtau at touchdown was different (mean tests) or more variable (SD tests) in certain visual conditions. An ANOVA was also used to test whether low angular head velocity prior to touchdown was different across the three visual conditions at 100 and 200 ms prior to touchdown. These tests were needed to indicate whether subjects had time to process visual information from the parvocellular pathway (for object identification) prior to landing.

Results

Judges’ Scoring

Although the judges were looking for similar attributes to score each performance, there was a difference in their rating that may have originated from their sport of expertise. However, a high correlation between the judges’ scores for each subject (mean $r = 0.76$, range $r = 0.66-0.86$; $p < .01$) showed that the difference in their rating techniques had little effect on the overall scoring pattern. Also note that for each subject, the trial receiving the highest (lowest) score from judge 1 was always the same as that receiving the highest (lowest) score from judge 2. Thus, mean score from the two judges were used in statistical analyses.

Effects of Reduced Visual Acuity

Changes in scores from NORMAL to REDUCED conditions were poorly correlated with reductions in acuity ($r = -0.37$; $t_4 = -0.81$, $p > .47$). This is clearly shown in Figure 2, which depicts the difference in mean performance score in the NORMAL and REDUCED conditions plotted against the reduction in acuity caused by the contact lenses for each subject. In one case, the reduction in acuity was associated with a decrease in performance score (subject 6). Note also that subjects with the greatest reduction in acuity did not have the lowest acuity after contact placement (see After column in Table 2).

Although not tested, all subjects reported that they spot during most of their performances. Subjects also reported that they thought it was more difficult to orient themselves while wearing the contacts than in the NORMAL condition and that wearing the contacts made everything “blurry” (subjects 1 & 2), “darker” (subject 3), or “weird” (subjects 2 & 5). When wearing the contacts, subject 3 noted that spotting did not seem to make a difference in his performance. This subject scored very well in the REDUCED condition (see subject 4 in Table 1). Unlike the other subjects, subject 6 had her worst performance (lowest mean performance score and 5 assists) while wearing the contacts (see Table 1). When performing in this condition, subject 6 tended to open her tuck early and land with the anterior aspect of her body directed toward the trampoline bed. During these performances, this subject noted that she kept mistaking the wall for the trampo-
Figure 2 — Difference in score (NORMAL – REDUCED) versus difference in acuity (before – after contact placement) is shown. Each point represents the mean score difference for the subject (1–6). A best-fit line is also provided.

line. This wall was located behind the subject at takeoff, was of similar color to the trampoline bed (excluding a red cross indicating the trampoline center), and was the last surface visible before the trampoline. It is likely that this subject, unlike the other athletes, used a different “visual” strategy when performing the back aerial double SSs.

Kinematics of Aerial Somersaults

Head, trunk, and neck kinematics during skill performance were viewed to provide insight on how subjects use vision to enhance performance. The trunk angular velocity patterns of the back double SSs with normal acuity (Figures 3A & 3B), reduced acuity (Figure 3C & 3D), and no vision (Figures 3E and 3F) were similar across all trials for each subject. The reduction in angular trunk velocity prior to touchdown differed among subjects (compare column 1 of Figures 3A, 3C, and 3E with column 2 of Figures 3B, 3D, and 3F) but was similar across the three visual conditions for each subject (within column 1 or 2 of Figure 3).

Angular head and neck (head – trunk) velocities differed for subjects in NO VISION trials during aerial somersaulting performances. Angular head velocity increased to a maximum shortly after takeoff in all conditions. During performance, most subjects maintained close to maximal angular head velocity until preparing for landing (column 1 in Figure 3), but subject 2 slowed his head after the first SS, then increased and decreased his head rotational velocity again on the second SS in trials when optical cues were available (Figures 3B & 3D). Note that in the data sets of figures 3A–D the head slowed faster than the trunk, due to rapid neck flexion, prior to touchdown when optical cues were available. During periods of
Figure 3 — Head (solid thin curve), trunk (dashed curve), and neck (solid thick curve) angular velocity for subject 4 and subject 2 during performance of the back double somersault in NORMAL (A & B), REDUCED (C & D), and NO VISION (E & F) conditions are shown. Neck angular velocity is the difference between head and trunk angular velocities. Stick-figures of head, trunk, thigh, and shank are drawn at three points (vertical lines). The first vertical solid line in each graph is placed at time = 0 for takeoff (TO), the second solid line is placed at the time of touchdown (TD), and the vertical dashed line represents the time at which angular head velocity drops below 6.98 rad/s just prior to touchdown. Knee and hip flexion seen in the stick figures at TO are the result of the trampoline surface rising with the subject prior to TO and occur after hip and knee extension were achieved. The two pluses (+) mark 100 and 200 ms prior to touchdown. Neck extension is positive, and flexion is negative.
head slowing, the anterior/posterior head axis was directed toward the trampoline bed in trials with normal or reduced acuity. Rapid neck flexion did not occur in most trials when optical cues were blocked (Figure 3F), but there were exceptions (Figure 3E). In most cases, if subjects slowed the head relative to the trunk just prior to landing in the NO VISION condition, this angular neck velocity was not as low as when visual cues were available (compare Figure 3E to 3A and 3C).

Figure 4 shows the mean low head velocity for doubles achieved by 100 or 200 ms prior to touchdown. Mean low head velocity was determined by recording

![Mean Low Head Velocity](chart)

**Figure 4** — Mean low angular head velocity achieved by 100 and 200 ms prior to touchdown is shown for the three visual conditions. Error bars represent 1 SE. Significant velocity differences between conditions are indicated with an asterisk.

![Performance Scores](chart)

**Figure 5** — Mean performance scores for all subjects are plotted across the three visual conditions (left). Mean scores without subject 6 are also plotted (right). Error bars represent 1 SE. Significant score differences between conditions are indicated with an asterisk.
the lowest angular head velocity reached after maximal head velocity occurred and prior to either 100 ms, which approximates the time needed to process optical flow information (Nashner & Berthoz, 1978), or 200 ms, the approximate time for object vision processing (Keele & Posner, 1968). Results showed that subjects reached similar low head velocities in conditions with normal or reduced acuity (100 ms, \( t_{17} = 1.17, p = .26 \); 200 ms, \( t_{17} = 1.42, p = .17 \)) and during all visual conditions prior to 200 ms before touchdown (\( F_{2,17} = 1.27, p = .31 \)). This was not the case when comparing NORMAL or REDUCED conditions to the NO VISION condition prior to 100 ms (NORMAL vs. NO VISION, \( t_{17} = 5.16, p = .00008 \); REDUCED vs. NO VISION, \( t_{17} = 3.99, p = .0009 \)). Thus, either head slowing may not be useful in the NO VISION condition or subjects may have trouble slowing head rotation when the visual cues are blocked during these performances.

Effects of Ocular Input on Performance Scores

Performance scores were influenced by visual condition (\( F_{2,103} = 4.23, p = .02 \)). Figure 5 shows that performance was better in the NORMAL condition than in the NO VISION condition (\( t_{103} = 2.9, p < .005, \text{power} = 0.99 \)), but that performance between REDUCED and NO VISION conditions (\( t_{103} = 1.8, p = .08, \text{power} = 0.39 \)) as well as NORMAL and REDUCED conditions (\( t_{103} = 1.15, p = .25, \text{power} = 0.17 \)) was similar. However, the individual data reveal that the similarity between REDUCED and NO VISION scores was strongly influenced by one female, subject 6, who performed back double SSs better without visual than with reduced acuity (Table 1, bold). The last column in Table 1 shows the mean performance score (+1 SD) for each subject in each condition. Analyses performed excluding data from subject 6 indicated that scores for the remaining subjects were worse in the NO VISION condition when compared to NORMAL (\( t_{88} = 4.72, p < .0001, \text{power} = 1 \)) and REDUCED (\( t_{88} = 4.03, p = .0001, \text{power} = 1 \)) conditions. Scores between NORMAL and REDUCED conditions remained similar (\( t_{88} = 0.13, p = 0.89, \text{power} = 0.07 \)). Given the current mean and SD for the mean difference in NORMAL and REDUCED conditions, 104 subjects would be needed to increase the power to 0.8. Thus with one exception, performance of double somersaults with normal and reduced visual acuity was better than when vision was occluded.

Use of External Assistance

An important issue to consider is whether external assistance given to athletes may have influenced judges scores if it prevented the athlete from falling, taking extra steps, and/or gave them more time in the air to complete the skill. Lower scores were observed when subjects were assisted during performances (\( F_{1,103} = 21.63, p < .0001 \)). The percent of trials with assistance for the three visual conditions are shown in Table 3. These results indicate that the number of trials in which assists were needed relative to those not needed were always highest in the NO VISION condition compared to conditions with normal or reduced acuity. Note also that the percent of assists in the REDUCED condition is elevated above the NORMAL condition because of subject 6 (Table 3). Percentages of assists in these conditions are similar (30% vs. 32%) when data from subject 6 are excluded.
Table 3  Percent of Trials Performed With Assistance

<table>
<thead>
<tr>
<th>Visual condition</th>
<th>% (number of trials)</th>
<th>Without subject 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORMAL</td>
<td>28.9 (45)</td>
<td>30 (40)</td>
</tr>
<tr>
<td>REDUCED</td>
<td>43.3 (30)</td>
<td>32 (25)</td>
</tr>
<tr>
<td>NO VISION</td>
<td>86.2 (29)</td>
<td>83.3 (24)</td>
</tr>
</tbody>
</table>

Note. The number in parentheses represents the total number of trials analyzed for the given skill in the given vision condition.

Landing Score

Because the landing is one of the direct items on which judges based their scores, it is not surprising that landing score had a strong correlation with performance score for each subject ($r^2 = 0.35$–$0.84, p < .01$). Figure 6 shows that higher landing scores, indicating more or larger steps or hops, were associated with poorer performance scores. In addition, the highest landing scores and lowest performance scores representing the poorest performance were found in the NO VISION condition (Figure 6). Since the landing is the last portion of the skill viewed, it is not surprising that correlations were high. The fact that correlations were not perfect ($r^2 < 1$) suggests that judges were scoring other attributes in addition to landings. Figure 6B shows that mean landing scores were similar for subjects 1–5 when comparing NORMAL and REDUCED conditions but different when these conditions were compared to the NO VISION condition (based on an ANOVA and Tukey's HSD post hoc test, $p < .05$). These data provide quantitative evidence that support the results based on qualitative scoring.

Angtau

Consistent with previous observations (Lee et al., 1992), the control variable Angtau was more variable for subjects in the NO VISION condition than in NORMAL and REDUCED conditions (Figure 7). Statistical analyses showed that the within-subject Angtau variability (SDs) differed across visual conditions ($F_{2,10} = 7.9, p = .004$). Post hoc testing verified that Angtau standard deviations were highest in the NO VISION condition ($p < .01$ for all comparisons), and were similar for NORMAL and REDUCED conditions ($p > .78$). These results suggest that subjects had the most difficulty controlling their body for landing when visual input was completely blocked. Differences in mean Angtau were not statistically significant.

Head Slowing

To better understand the role of vision in control of head slowing, it is important to note a possible neck muscle pre-activation period from some critical point during performance to touchdown. We have already reported that subjects' angular head velocity is slowed to a greater extent just prior to landing in NORMAL and REDUCED conditions when compared to the NO VISION condition. In fact, in 35% of the trials with normal and reduced acuity, subjects probably had time to process
parvocellular information and prepare for landing. This is because in conditions where visual cues were available (NORMAL and REDUCED), angular head velocity reached less than 6.98 rad/s (the maximum head velocity for gaze stabilization, Pulaski et al., 1981) at or before 200 ms prior to touchdown. In most of these trials, subjects may have had time to stabilize their gaze, possibly identify objects, and better prepare for landings. But even when gaze is fairly stable (i.e., head and eye velocity are equal in amplitude and opposite in direction), it may have been difficult for subjects to identify objects, because visual acuity degrades with increasing head velocity (Lee et al., 1997). However, head slowing (<6.98 rad/s) was achieved in 83% of the trials at or before 100 ms prior to touchdown. Although this time is inadequate to process object vision, it is enough to process
optical flow information. Thus, it is possible that slowing the head may enhance use of optical flow information (see Discussion).

Discussion

We wanted to test the theory that optical input processed through the parvocellular and magnocellular visual systems are both necessary for acrobats to perform their best in back aerial double somersaults. Our results provide some evidence that refute this theory, suggesting that vision typically used for object identification is not necessary for best performances of this skill. The implications of these results for visual control over head and body orientation during aerial somersault performance are discussed.

Similar performance in conditions with normal and reduced acuity for 5 of 6 subjects provided evidence that object vision was not required for the acrobats' best back aerial somersaulting performances. Although level of visual acuity differed across subjects while wearing the contacts (Table 2), scores for trials while wearing the contacts were comparable to those with normal acuity in most subjects (Table 1 and Figure 2). Furthermore, these subjects needed assistance on a similar percentage of trials when performing in NORMAL and REDUCED conditions (Table 3), and exhibited similar patterns of head slowing kinematics (Figure 3). It should be noted that when wearing the special contacts, not only is acuity, and therefore object vision ability, reduced but so is part of the optical flow input. Since the magnocellular system utilizes both the central and peripheral viewing fields (Goodale & Milner, 1992; Trevarthen, 1968), occlusion of this central portion
could reduce performance levels even if subjects only depend on optical flow information. The novelty of wearing the contacts may have also produced slight reductions in scores and increases in the number of assists. The fact that some subjects scored higher while wearing contacts than in the NORMAL condition (Table 1) may indicate a practice effect, since the REDUCED trials were always performed last. However, the similarities identified in performances with normal and reduced acuity strongly support the suggestion that object vision is not necessary for best aerial performances by these acrobats.

Complete removal of vision clearly degraded performance of the back aerial double SS. These findings extend previous reports of poorer performance when optical cues are eliminated during aerial SSs (Bardy & Laurent, 1998; Lee et al., 1992; Rezette & Amblard, 1985; Yeadon & Mikulcik, 1996). Performance degradation was seen in lower performance scores (Figure 3 and Table 1) and a higher percentage of NO VISION trials, where subjects needed external assistance (Table 3). Thus, some optical input was necessary for high and consistent performance levels in the back aerial double SSs.

Because there were many more assists during somersaults performed without vision than when vision was allowed, it is likely that assists reduced differences in mean scores between NO VISION and visual performances. Although subjects’ scores were lower when external assistance was given, it is quite possible that the extra assistance given to the athletes increased their performance scores. If a subject was assisted before landing, cutaneous input from contact with the spotting belt may have provided additional cues. It is also possible that external assistance prevented extra steps and/or falls after touchdown that would have occurred if the subject was not assisted. In either case, external assistance could have falsely increased performance scores, which would produce greater similarities across the three visual conditions. Because the percentage of assists was much higher for NO VISION trials, scores were probably increased most in this condition. Thus, although our statistical analyses adjusted for confounding of assistance, the actual differences in performance with and without optical input would likely be more dramatic than reflected in the mean scores reported here.

One criticism of the current study could be that we never experimentally verified that our subjects use spotting techniques in their normal training and performances. It has been shown that what subjects perceive is not always in agreement with their actions. In one report, subjects oriented themselves closer to the gravitational vector, as requested, even when gravitational and balance vectors were located at different orientations (Riccio et al., 1992). When their body orientation was between these two vectors, subjects often perceived that the gravitational vector was in the direction of balance and not in its true location. All our subjects reported that they use spotting to help orient themselves during their training and competitive performances. We do not dispute the anecdotal reports of acrobats identifying objects while airborne. The real concern regarding such reports has to do with the time required to process such information.

It is clear that reducing visual acuity does not prevent subjects from identifying larger objects. As mentioned previously the task of identifying the trampoline during some performances was not always within a subject’s ability as identified by subject 6. The difficulty that this inability produced for one subject did not seem to be a problem for others. Whether this difference is due to using a different “visual” strategy or lower performance ability is unclear. It could be that other subjects were able to identify the trampoline and use this information as in normal
acuity conditions. It seems more likely that other subjects did not need to use object vision for their best performances, especially since only one subject had better acuity than subject 6 when wearing the special contacts (see Binocular Acuity, After in Table 2). Further evidence to support this conclusion will be presented.

When optical input was available, subjects had the opportunity to stabilize their gaze before touchdown. It has been shown previously that in some subjects, gaze stabilization can occur if angular head velocity is less than 6.98 rad/s (Pulaski et al., 1981). In the present study, angular head velocities less than 6.98 rad/s prior to touchdown were found in all but one trial with normal or reduced acuity. Note that if head slowing does not occur in time to the process the information and prepare for landing, then such information cannot be used to improve performance at this stage.

In trials with normal and reduced acuity, there was always time to process optical flow information but not to process object vision. Head slowing (<6.98 rad/s) occurred greater than 200 ms (the time required to process object vision) prior to touchdown in only 35% of the NORMAL and REDUCED trials. These data support the earlier statement that subjects 1-5 do not use object vision for their best back aerial double SS performances. In 83% of all NORMAL and REDUCED trials, head angular velocity slowed to less than 6.98 rad/s by 100 ms (the time required to process ocular flow information) prior to touchdown. Thus, for most trials where optical input was available, stabilization of gaze could occur prior to 100 ms before touchdown.

Why would subjects try to slow their heads faster than the trunk if not for object identification? There are three possible reasons why subjects may slow their heads during aerial SS performances. First, subjects may try to stabilize their gaze, which has previously been shown to reduce vertigo and nystagmus that are induced during rapid rotations and would degrade performance (Collins, 1966, 1968; Kameswaran & Rajender Kumar, 1972; Marshall & Brown, 1967; McCabe, 1960; Mowrer, 1937; Osterhammel et al., 1968; Tschiassny, 1956). Second, head slowing during somersaulting performance may enhance optical flow processing by slowing the optical flow field relative to a body-fixed spatial reference frame. Third, subjects may need to identify an external target visually to determine their head and body orientation relative to it. This study provides evidence that vision for precise object identification is not needed for best performance of back double somersaults and that collegiate acrobats clearly perform better when some visual cues are available. Similarities were seen in head, neck, and trunk kinematics for trials in the two conditions in which optical input was allowed. This evidence and the available processing time provide further support for the idea that only vision from optical flow information is needed for high level aerial somersaulting performance. Thus, we suggest that head slowing in aerial SSs is needed to enhance optical flow processing and suppress effects of vertigo and/or nystagmus, which in return improves performance of aerial SSs.

The presented kinematic data provide some evidence that acrobats control head orientation during aerial somersault performances. The difference in head and neck angular velocities between NO VISION and NORMAL or REDUCED trials provides some evidence that such control was partially due to either reflexive or voluntary use of neck muscles. Slowing the head to decrease the relative velocity in optical flow information is probably necessary for appropriate coordination of muscles (body control) when landing aerial skills. Evidence of visual use for body control was presented in the results, showing that Angtau, the
angular time-to-contact variable at touchdown, was more consistent in trials when subjects’ vision was not completely occluded. These data are in agreement with other reports of greater variability in similar time-to-contact variables for acrobats performing front (Lee et al., 1992) and back (Bardy & Laurent, 1998) single aerial somersaults while blindfolded.

In conclusion, most acrobats perform the back aerial double somersault better when some optical cues are available. The college-level varsity acrobats in this study did not need to identify objects for the best performance of this skill. Kinematic data showed that these acrobats slow the head just prior to landing, probably to enhance the use of optical flow information and to stabilize gaze to reduce the effects of vertigo and nystagmus, and thereby improving landing performance. Nevertheless, we cannot exclude the possibility that higher-level (e.g., olympic-class) acrobats need to use object vision to produce their best performances. That is, olympic-class athletes may slow the head sufficiently more than 200 ms before ground contact to permit spotting and object identification for the best performance.

References


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