Different temporal bases for body and arm movements in volleyball serve reception

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In many sports, successfully intercepting a ball requires players to move both their body and their arms. Yet, studies of interception typically focus on one or the other. We performed an analysis of the moments of first foot and arm movements of elite-level volleyball players during serve reception. Video footage of five international matches of the Netherlands men’s national volleyball team allowed the systematic coding and analysis of 347 different serve reception events. For each event, we identified the time of serve (TS) and time of contact (TC). Ball flight time (from TS to TC) varied between and within types of serve (power jump serves, \( n = 193 \), and jumping float serves, \( n = 154 \)). Correlation analyses revealed that foot movement was initiated with respect to time from TS, while arm movement was initiated with respect to time until TC. These results suggest that whole-body and arm movements rely on different control processes.

In many sports, players are repeatedly faced with the challenge of intercepting moving targets. A volleyball player steps into the ball trajectory to pass an oncoming serve, a tennis player crosses the court to hit a return, and a baseball player runs to catch a fly ball. Although these actions are seemingly different, they have at least one aspect in common: whole-body displacement participates in achieving the goal of bringing the upper limbs (volleyball) or an extension thereof (racket in tennis, glove in baseball) into contact with the ball. The issue that we address in the current contribution is whether in such interceptive movements, the whole-body and arms are controlled on the same or on a different temporal basis. For this purpose, we studied volleyball players’ behavior during the reception and subsequent passing of a serve in volleyball.

After a serve in volleyball, the defending player who intends to receive the serve has to move into the ball’s trajectory and place the arms in such a way as to intercept (and pass) the ball. This has to happen quite quickly: for instance, a power jump serve – the fastest type of serve – takes on average 0.7 s to arrive at the passer (Agelonisidis, 2004). Receiving a volleyball serve, therefore, can be regarded as a time-pressured interceptive action involving both whole-body movement (i.e., a locomotor component) and arm movement (resulting in final contact with the ball).

Previous research into the control of interception in volleyball is scarce. Lenoir et al. (2005) studied the effects of ball spin and color patterns on receivers’ lateral movement patterns. Interestingly, to describe the interceptive actions, they measured foot action (against a force plate) to determine movement onset and head motion (from video-based motion capture) to determine movement amplitude. Although both body parts admittedly appear to be related to whole-body movement, the possibility that both these distinctive aspects of the interception movements might be controlled differently and with respect to other key moments of the serve was not considered. In other words, the assumption was that examining the control of feet and head movement was equivalent. At the same time, while foot movement initiation times and head movement amplitudes indeed most likely both address the locomotor component of the interceptive action, arm movements (which are an important aspect for the final interception) were not considered. It is noteworthy in this respect that previous studies on interceptive actions have typically been restricted to a single aspect of interception: head movements for slower, whole-body interceptive movements (e.g., Lenoir et al., 1999; Chardenon et al., 2004, 2005; Fajen & Warren, 2004; Bastin et al., 2006) and hand movements for faster, manual interceptive actions (e.g., Peper et al., 1994; Montagne et al., 1999; Jacobs &
Michaels, 2006; Dessing & Craig, 2010; Ledouit et al., 2013). This suggests that whole-body and arm movements might not be controlled in the same way.

The approach that we take in the present study is that serve reception in volleyball involves both whole-body and arm movement, which each might be controlled with reference to one of two key moments of the serve; either the moment of serving (the start of the ball flight) or the moment of passing (the end of the ball flight). For instance, it could be that whole-body movement would be controlled in relation to the start of the serve, whereas the final interception with the arms is controlled in relation to the actual passing (i.e., the end of the serve). To this end, we inspected video data of elite-level volleyball and extracted the movement initiation times of the arms and the feet during serve reception. We examined feet and arm movement initiation times with respect to the two temporal key moments of the serve, to see whether these movements are controlled on the same or on a different time basis.

Methods
Sample
We analyzed five matches of the Netherlands men’s national volleyball team. The matches had been recorded with a digital camera (Canon Legria HF 200; 25 Hz, Canon, Tokyo, Japan), by the team’s video scout, during international tournaments in the period from August 2011 until September 2012. The camera was situated minimally 10 m behind the court and was positioned in such a way that, after zooming, it provided a clear view of the nearest half of the field. During three of the matches, the camera rested on a tripod at a height of 1.50 m; it was positioned at a height of 5 m during the other two matches. For our analyses, we only considered serves delivered from the opposite side of the field, that is, serves approaching the camera. Approval for using the taped material and anonymously analyzing the serves was obtained from the coach of the National team.

Video coding and dependent variables
Using The Observer XT 10.5 software (Noldus, Wageningen, the Netherlands), we coded several aspects of each serve-pass event. First, we noted the type of serve. Second, we determined the moment of serving, the moment of first movement of the feet, the moment of first movement of the arms, and the moment of passing. The moment of serving (time of serve, TS) was identified as the video frame at which the server’s hand contacted the ball. The moment of passing (time of contact, TC) was identified as the video frame at which the receiver’s arms contacted the ball. Ball flight time was defined as the time between the moments of serving and passing. Movement initiation of the feet was defined as the first movement of a foot resulting in sustained body movement toward the ball after serve delivery. Steps initiated before serve contact were excluded. The first movement of the arms relative to the body that resulted in ball contact was taken as the moment of arm movement initiation. When using an underhand technique for passing, the arms would typically start to move to form a “platform”; when an overhand technique was used for passing, the initial arm movement would be directed upwards. Because players generally start with their arms open to their side, the arms were clearly visible on the video recordings, which contributed to an accurate identification of the moment of arm movement initiation.

Movement initiation times of both feet and arms were determined both relative to TS and relative to TC. Finally, we considered a pass to be successful when it arrived at the setter in a 2 by 3.5 m area, on the right side of the court, touching the centerline and the net on its short and long sides, respectively. Balls arriving in this area, in principle, allowed the setter to achieve full offensive strength.

All serve-pass events were coded by the same observer. In order to determine coding reliability, two additional observers independently coded 70 serve-pass events from one of the matches. Intraclass correlations for flight times and for movement-initiation times of the feet and arms were 0.996, 0.818 and 0.867, respectively.

Serve and pass characteristics
The video footage contained a total of 502 incoming serves. Three types of serve were observed: power jump serves (serves in which the player, after a high ball toss and a high, accurately timed jump, strikes at the top of the ball with a wrist span, causing the ball to spin and move at a high speed toward the receiver), jumping float serves (serves in which the player tosses the ball several meters in the air before he jumps submaximally and hits the ball with a flat hand, causing it to ‘float’ through the air without spin, resulting in a serve with a more unpredictable flight trajectory), and standing float serves (serves comparable with the jumping float serve, but instead of jumping, the player remains standing on the floor). Because there were only two standing float serves, we decided to exclude these from the analyses. Of the remaining 500 serves, 172 were jumping float serves (simply referred to as float serves from here on) and 328 were power jump serves (simply referred to as power serves from here on). Aces were observed for two float serves (1.2%) and nine power serves (2.7%); faults were observed for 13 float serves (7.6%) and 85 power serves (25.9%). Because the receiving player never contacted the ball for these 109 aces and faults, these serves were not used in the analyses of foot and arm movement initiation times. A further 44 serves were excluded because the ball touched the top of the net (three float serves and 22 power serves) or because the moment of movement initiation could not be determined (0 float serves and 19 power serves).

Of the 347 serves included in the analyses, 154 were float serves and 193 were power serves. Float serves were passed using the underarm technique in 115 cases (74.7%) and using the overhand technique in 39 cases (25.3%). Power serves were always passed using the underarm technique. Passing was successful for 85 float serves (55.2%) and 78 power serves (40.4%).

Results
Figure 1 presents the distributions of ball flight times for the float serves (M ± SD: 1.04 ± 0.12 s) and the power serves (0.69 ± 0.13 s) separately. A t-test revealed that flight times were different for these two types of serve, t(345) = 25.52, P < 0.001.

The initiation times of the first foot and arm movements are summarized in Table 1. On average, the arms started moving later than the feet, as demonstrated by a paired t-test, t(346) = 9.84, P < 0.001. Separate analyses for the float and power serves, however, revealed that this difference in foot and arm movement initiation times was only observed for float serves, t(153) = 16.76, P < 0.001, and not for power serves, t(192) = 0.14, P = 0.89 (Fig. 2(b) and (d)).

As can be seen from Fig. 2, TS-related foot movement initiation time correlated weakly with ball flight duration...
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(r = 0.21, P < 0.001, panel a), whereas TS-related arm movement initiation time correlated strongly with ball flight duration (r = 0.77, P < 0.001, panel c). When both types of serve were considered separately, TS-related foot movement initiation time did not significantly correlate with ball flight duration (r = −0.07, P = 0.418 and r = 0.07, P = 0.309, for float and jump serves, respectively) whereas TS-related arm movement initiation time did (r = 0.45, P < 0.001 and r = 0.51, P < 0.001, for float and jump serves, respectively). In addition, TS-related foot movement initiation times were less variable (SD = 0.10 s) than TS-related arm movement initiation times (SD = 0.20 s). This pattern was also observed for the float and power serves separately (see Table 1).

Figure 3 paints the opposite picture for TC-related movement initiation times. Overall, TC-related foot movement initiation time correlated strongly with ball flight duration (r = 0.89, P < 0.001, panel a), whereas TC-related arm movement initiation time correlated more weakly with ball flight duration (r = 0.42, P < 0.001, panel c). Separate analyses for the two types of serve again corroborated this systematic difference. Correlations between TC-related foot movement initiation time and ball flight duration were strong for both the float serves (r = 0.75, P < 0.001) and the power serves (r = 0.82, P < 0.001). Correlations between TC-related arm movement initiation times and ball flight duration were weaker for both float serves (r = 0.37, P < 0.001) and the power serves (r = 0.49, P < 0.001), respectively. In addition, TC-related foot movement initiation times were more variable (SD = 0.22 s) than TC-related arm movement initiation times (SD = 0.14 s). Again, this pattern was also observed for the float and power serves separately (see Table 1).

Discussion

The goal of the present contribution was to examine whether foot and arm movements were controlled on the same temporal basis or not. To this end, we observed – in real match plays – movement initiation times of both the feet and arms of elite-level volleyball players receiving a serve, and subsequently passing the ball to the setter. The analyses revealed that movement of the feet and arms are initiated with reference to different temporal key moments of the serve-pass event. The start of foot movement seemed timed with respect to the moment of serving and the start of arm movement timed with respect to the moment of ball contact for passing.

Although ball flight times varied substantially, first movements of the feet were always seen at an average of roughly 0.3 s after the serve had been delivered, irrespective of type of serve (see Fig. 2(b)). Relatedly, TS-related foot movement initiation demonstrated low variability and did not systematically vary over different ball flight durations. Foot movement, therefore, appears to be initiated at a more or less constant time from the beginning of the serve. Analogously, TC-related arm movement initiation also demonstrated low variability and did not systematically vary over different ball flight durations. These results seem to indicate that, irrespective of the type of serve, the arms started to prepare themselves for passing at a more or less constant time before ball contact (on average around 0.4 s; see Fig. 3(d)). Combining these results, the inference would be that interceptive movements of the feet and arms are initiated with respect to different temporal key moments of the serve: the beginning of ball flight (i.e., TS) and the end of ball flight, which is the moment the receiving player contacted the ball (i.e., TC), respectively (Fig. 4).

To understand the control of intercepting a volleyball serve, the finding that whole-body movement and arm

![Fig. 1. Frequency distributions of ball flight times for the float (n = 154) and power (n = 193) serves.](image)

Table 1. Means (M) and standard deviations (SD) of initiation times of feet and arm movements in reference to the time of serve (TS) or the time of contact (TC)

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<td></td>
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</tr>
<tr>
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<td>0.39</td>
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<td></td>
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<td>Arms</td>
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<td>M(s)</td>
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<tr>
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movement are controlled on a different temporal basis seems critical. Interestingly, models for the control of interception developed in the context of arm movements often include time-to-contact variables (e.g., Bootsma et al., 1997; Montagne et al., 1999; Jacobs & Michaels, 2006; Dessing & Craig, 2010). This fits well with the current findings that the initiation of arm movement is tied to the moment of receiving the serve. Whole-body displacements, on the other hand, were initiated at a roughly constant moment after serve delivery. This might be the time needed for a volleyball player to recognize the ball trajectory and to initiate the locomotor (transport) component for setting up an adequate interceptive action. The mean feet movement initiation time found in our study (0.29 s) corresponds to movement initiation times found in other studies of serve reception in volleyball (experts 0.25 s and nonexperts 0.27 s; Lenoir et al., 2005) and of fly ball catching (experts 0.35 s and nonexperts 0.27 s; Oudejans et al., 1997). Thus, it seems that people need about 0.3 s to respond to the movement of approaching projectiles. In fly ball catching, a distinction between running to the interception location (whole-body movement) and actual catching (arm movement) has been proposed (Michaels

Fig. 2. Scatter plots showing the relation between ball flight time and TS-related movement initiation of foot (a) and arm (c) for both types of serve. Frequency distributions of TS-related movement initiation of foot (b) and arm (d) for both types of serve.
When considering the time that participants needed to initiate their running to catch approaching fly balls, Oudejans et al. (1997) looked at both the feet and the head. While both may be considered to be related to the locomotor component, feet movement was initiated earlier than head movement. Furthermore, the expert catchers in the study seemed to wait a little longer before they started moving, but always started moving in the right direction. Faster movement initiation times of the feet were seen in the nonexpert catchers of the study. However, the faster responses were often false starts by the nonexperts, initiating movement in the wrong direction. In other words, the movement initiation times of feet and head seemed to tap into different processes: feet movement related with quickly responding to the launching of the fly ball and head movement related with an informed decision to move in the right direction (cf. Oudejans et al., 1997). In summary, for the type of inferences that can be made with respect to the operative control, it matters on which part(s) of the body we, as experimenters, focus our attention.
Perspectives

Receiving a serve in volleyball involves both whole-body displacement and arm movement. The distinction between whole-body displacement starting some 0.3 s after serve delivery and arm movement starting about 0.4 s before serve reception might be taken to suggest a sequential order of the two types of movement. Receiving and passing a serve in volleyball would start with bringing the body into the vicinity of the interception location, after which the final arm movement can be supported by a stable posture. Indeed, this sequential perspective is at the basis of training the skill of receiving a volleyball serve (e.g., see Dearing, 2003; Papageorgiou & Spitzley, 2002; Shondell, 2002). For the slower serve speeds, as in the float serves in the present study, the sequence of body displacement first, followed by arm movements, is indeed what we observed. In many cases, however, jump serves were delivered. In comparison to float serves, jump serves arrive faster at the defender (around 0.7 s instead of 1.0 s, respectively), making it hardly possible to first move the whole body for a stable support of arm movement. In these instances, players often had no other choice than to divert to performing their passes while still moving their body. This is not the textbook way of receiving a serve; yet, at least at the level of expertise considered in the present study, this unorthodox way of passing is not an exception at all. Considering that players do often face the situation that they will have to receive a jump serve that does not allow them to complete their body movement before performing their arm movement might be important in the design of volleyball practice. Furthermore, the study of the effects of having to pass a serve in more unorthodox ways on the efficacy of properly getting the ball to a setter, and ways to improve this efficacy seems to be a welcome future exercise.

Key words: Motor control, interception, timing, ball sports.

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