Exp Brain Res (2010) 206:409–417
DOI 10.1007/s00221-010-2421-1

RESEARCH ARTICLE

Catching a gently thrown ball

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Received: 22 January 2010 / Accepted: 8 September 2010 / Published online: 23 September 2010

Abstract Several studies have shown that people can catch a ball even if it is visible only during part of its flight. Here, we examine how well they can do so. We measured the movements of a ball and of the hands of both the thrower and the catcher during one-handed underarm throwing and catching. The catcher's sight was occluded for 250 ms at random moments. Participants could catch most balls without fumbling. They only really had difficulties if vision was occluded before the ball was released and was restored less than 200 ms before the catch. In such cases, it was impossible to accurately predict the ball's trajectory from motion of the ball and of the thrower's hand before the occlusion, and there was not enough time to adjust the catching movement after vision was restored. Even at these limits, people caught most balls quite adequately.

Keywords Interception · Motor control · Time to contact

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Introduction

People's ability to catch a ball that is thrown gently to them from a short distance is amazing if one considers how little time there is to plan the movement and to get the hand to the correct position. The ball's trajectory can only really be predicted once it leaves the thrower's hand. Nevertheless, a rough estimate of when and where the ball could be caught can be obtained even before this, from the movement of the thrower's arm. Once the ball leaves the thrower's hand, its trajectory is predictable. However, considering the imprecision in judging the position, velocity and (gravitational) acceleration of the ball, and in combining these judgments, this initial prediction is presumably not very accurate. To compensate for this, the prediction is continuously updated as the ball approaches, and the movement adjusted accordingly. To examine whether this account of catching is tenable and whether there are moments at which seeing the ball is particularly important, we examine how catching performance depends on the times at which visual information is available.

We use an unrestrained slow underarm throwing and catching task. This task provides the opportunity to use many kinds of information, from the thrower's posture before release up to visual information from the ball as the hand closes on it. By constraining the task, one can make people rely on specific kinds of information at particular times. If subjects are required to initiate a pre-programmed movement at a critical moment (Tresilian and Houseman 2005), they will primarily response to visual information that helps them judge that moment. If the conditions make it hard to predict the ball's trajectory, then the prediction will constantly change so that vision remains essential until the very end (Peper et al. 1994; Montagne et al. 1999). If vision is only available very briefly, it can best be available as late as possible, when it is most reliable, but leaving enough time to respond (Amazeen et al. 1999). In elementary slow underarm throwing and catching, there are relatively few constraints, so this task is suitable for evaluating the overall value of information at different times.

Several studies have examined how well people can catch a ball if only a part of the trajectory is visible (Dessing et al. 2009; Sharp and Whiting 1974, 1975; Whiting and Sharp 1974). These studies have shown that it is advantageous to see the ball longer, but that the time when one sees the approaching ball is not very critical, except that whether one sees it from about 200 ms before the catch is irrelevant because from that moment there is no longer enough time to respond to new information (Sharp and Whiting 1974; McLeod 1987). We elaborate on the issue of how catching depends on the time during which visual information about the ball is available by removing information briefly at various moments. Rather than only evaluating the success in catching the ball, we also evaluate the quality of the catch. Considering evidence that our brain can make reasonably reliable spatial and temporal estimates of future states of the environment (Hayhoe et al. 2005; Indovina et al. 2005; Zago et al. 2009) and of our own movements (Blakemore et al. 1999), we were particularly interested in the use of information from near the moment the thrower releases the ball.

We measured the movements of a ball and of two people's hands as they threw the ball back and forth. By removing vision at unpredictable moments, we examine the extent to which the resolution of information at various times is good enough to allow people to perform a good catch. We assume that success only depends on the sensory resolution and the delays involved in acquiring the information and transforming it into an appropriate action. The results suggest that people can already predict the ball's trajectory well enough to catch it if they see the ball's movement until it leaves the thrower's hand. If the catcher has some idea of when the ball will arrive, then seeing it from about 200 ms before the catch is enough to catch the ball without fumbling.

Materials and methods

Apparatus

An Optotrak 3020 3-D motion capture system (with two sensor-bars; Northern Digital, Waterloo, Ontario, Canada) was used to record the positions of a ball and of the thumbs and index fingers of the right hands of a thrower and a catcher. The ball had a diameter of 73 mm and a mass of 176 g and was fitted with six infrared emitting diodes (IREDs) distributed evenly across its surface. These IREDs were powered by a battery and synchronized by telemetry so that there were no wires attached to the ball. The positions of the ten IREDs (six for the ball; two for the catcher's hand; two for the thrower's hand) were recorded at 100 Hz. The catcher's vision was occluded for 250 ms intervals using PLATO LCD spectacles (Milgram 1987) that block vision without changing the overall luminance. The 250 ms periods of occluded vision were separated by periods with normal visibility with a random duration between 800 and 1,000 ms. Figure 1 shows the trajectories of all ten IREDs during a single throw. Dotted lines denote positions when the spectacles occluded the catcher's vision.

Participants and procedure

Within each session, two participants continuously threw the ball back and forth for 10 min. Although both participants threw the ball and caught the ball, the participant whose vision was intermittently occluded by the PLATO spectacles will be referred to as the catcher and the other as the thrower because we are only interested in performance when the participants had those roles. The first author was always the thrower. The second and third authors and two people who were unaware of the precise purpose of the study participated as catchers. The average distance between where the thrower released the ball and where the catcher caught it was 75 cm ($\sigma = 16$ cm). All participants had normal (corrected) acuity and normal binocular vision. All except for the first author were members of the Faculty of Human Movement Sciences in Amsterdam. The local ethical committee approved the study. Each participant took part in three sessions except for the second author who took part in six sessions.

Data analysis

Release and catching points

The first step in our analysis was to find the release and catching points. In order to do so, we first determined the average distance between the two IREDs on the hand and all visible IREDs on the ball. The inset of Fig. 1 shows an example of how this variable changes as the ball is thrown back and forth. Green and red lines correspond to the hand of the thrower and catcher, respectively. The period during which each participant was holding the ball is easily recognized because the distance between the ball and the hand is small and remains constant. We used a distance threshold of 70 mm to identify approximately when the ball must have been caught and thrown and conducted further analyses to precisely determine these moments.

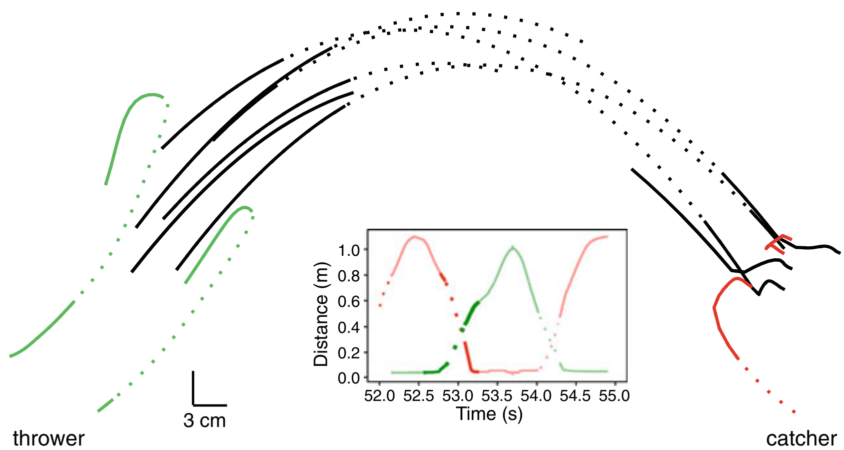

Fig. 1 *Side view* of one throw. The *black curves* show the trajectories of the six IREDs on the ball. The *coloured curves* show the trajectories of the IREDs attached to the index finger and thumb of the thrower (*light green*) and catcher (*dark red*), respectively. The *curves* are *dotted* during the interval in which the catcher's sight was occluded in this particular trial. There are gaps in the trajectories whenever the position of that IRED could not be determined because it disappeared from view as the ball or hand rotated, or as the participant's hand occluded the ball or vice versa. The *inset* shows the change in distance between the hand and the ball when the ball is thrown back and forth (*green* and *red lines* are for the thrower and catcher, respectively). The *dotted sections* indicate when the catcher's spectacles were closed. The *highlighted section* corresponds to the paths shown in the main figure (colour figure online)

The moment at which the thrower released the ball was determined by finding the peak velocity of the ball. Since the ball was thrown upwards, it obviously started decelerating as soon as it left the palm of the hand. From Fig. 2a, it would appear that the hand starts to slow down slightly before the ball is released. This is because we consider the average position of the finger and thumb to be the position of the hand, rather than the position of the palm of the hand. The thumb and index finger move slowly in opposite directions for some time before the ball loses contact with the palm of the hand (see red triangles). As they do so, the midpoint between them moves slightly back with respect to the ball, giving the impression that the hand is slowing down.

Determining the moment of the catch is less straightforward, especially for clumsy catches. We estimated the palm of the catcher's hand's first contact with the ball by analysing the changes in distance between each IRED on the catcher's hand and each IRED on the ball. We averaged the absolute values of these changes across all pairs of IREDs. This measure has a value of zero when the ball is held stably in the catcher's hand. Its value fluctuates gradually as the ball flies through the air, and the hand first moves towards the ball and then moves back along with the ball to reduce the relative speed when they make contact. From about 75 ms before contact, when the ball is about 20 cm from the hand, the value declines rapidly. At the same time, the distance between the finger and thumb also decreases rapidly. Part of the reason for the rapid decline in the average absolute distance between the pairs of IREDs is geometrical. It is the result of the markers on the ball not moving straight towards the digits. As the ball falls into the palm of the hand, many of the IREDs on the ball will be moving almost perpendicular to the line connecting them to the digit, so that the distance hardly changes when the ball moves. We fit a line to the rapidly declining section of the change in distance (when its value was between 15 and 0.2 mm/s; see red lines in Fig. 2b, c) and regarded the time when this line reached the value of zero as the moment of the catch. When the ball was dropped, we used the time at which the ball was closest to the digits as our estimate of the moment at which it was 'caught'.

Identifying drops and quality of performance

Catching behaviour ranges from perfect catches, with the ball staying firmly in the hand from the moment of contact, to drops, with either no contact with the ball at all or the ball bouncing off the hand after impact. Between these two extremes is a whole range of clumsy catches. We quantify the quality of the catch with a measure that has a value of 100% for a perfect catch and 0% for a drop (irrespective of whether the hand touched the ball). Drops were easily recognized because the ball moved well below the height of the hand without the distance between the hand and the ball reaching the constant minimum value that characterizes a catch. Moreover, the next throw was clearly delayed. The quality of successful catches was defined by identifying how stable the ball was within the hand during the first 300 ms after the first moment of contact. We relied on the average squared value of the change in distance between the IREDs on the hand and the ball to characterize the clumsiness of the catch. For a good catch, this value was about zero, because the ball remained firmly in the hand from the

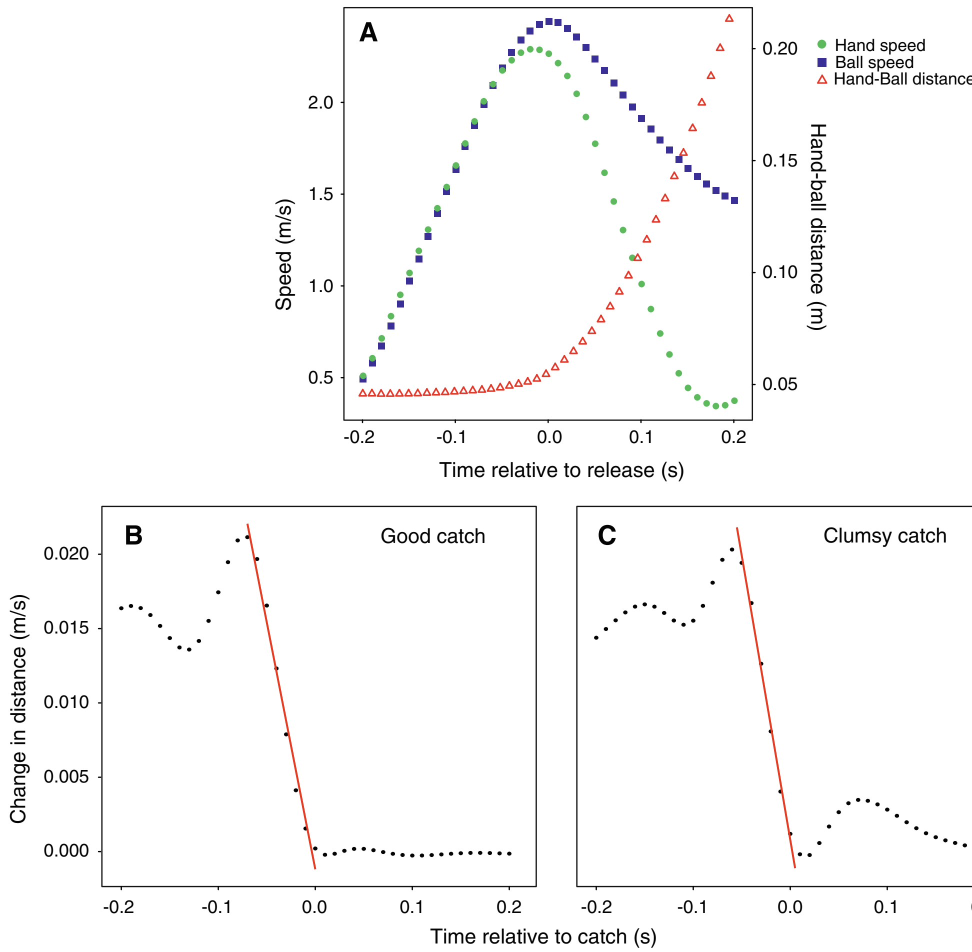

Fig. 2 **a** Speed of the thrower's hand (*green discs*; *left axis*) and of the ball (*blue squares*; *left axis*) and distance between the thrower's hand and the ball (*red triangles*; *right axis*) as a function of time relative to release (zero denotes the time of release). **b**, **c** Example of the rate at which the average distance between the IREDs on the catcher's hand and those on the ball decreases for a good (**b**) and a clumsy (**c**) catch as a function of the time relative to the catch (zero denotes the moment of the catch). The *red lines* are linear fits used to estimate the moment of the catch. The latter is the time at which these *red lines* intercept a change in distance of zero (colour figure online)

moment of contact until it was thrown back to the thrower (Fig. 2b). On clumsy catches, the distance between the ball and the hand fluctuated just after the first contact as the catcher fumbled to get a stable grip on the ball (Fig. 2c). To relate such fumbling to drops, the average change in squared distance during the first 300 ms after contact for each catch was normalized by dividing it by the value for that participant's most clumsy catch, and this normalized value was subtracted from one. In this way, perfect performance was assigned a value of 100%, and each participant's most clumsy catch was considered to be equivalent to dropping the ball and was assigned a value of zero.

Results

Overall we analysed 3,449 throws, 86 of which were drops. On average, the throwing movement took 258 ms from the moment the thrower's hand started moving forward until the moment the ball was released. The ball then spent about 483 ms in the air before the catcher caught it. The variability in the ball's flight time (within a session) was about 51 ms. Figure 3 shows how the quality of the catch depended on the timing of visual occlusion. The left panel shows how it depends on when the spectacles closed relative to when the thrower released the ball. The right panel shows how it depends on when the spectacles opened relative to the time of the catch. As there is variability in the flight time of the ball, the two panels are not precisely identical (except for a shift in the time axis). The symbols and thick curves show average values of all participants. The thin curves show individual participants' data. Performance was poorest when the spectacles shut just after the ball was released (left panel) and reopened about 200 ms before the catch (right panel). Even then, though, the catches were generally quite good.

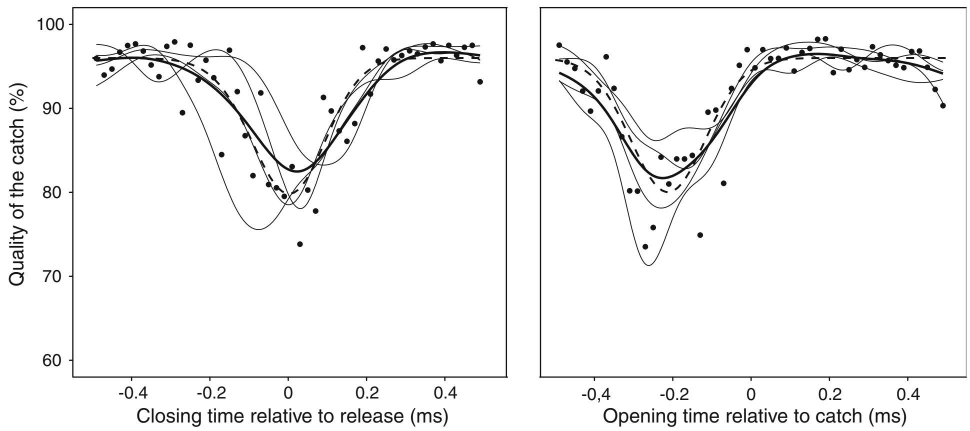

Fig. 3 Quality of the catch as a function of how long after the ball was released the spectacles closed (*left panel*) and how long after the ball was caught the spectacles opened (*right panel*). The points show means within 20 ms bins, averaged across the four catchers. The *thick curves* show smoothed versions of the data (averaged across time with weights defined by a Gaussian window with a width of 25 ms). The *thin curves* show smoothed data for individual catchers. The *dashed curves* show the fit of our simple model (Eqs. 2, 3 for *left* and *right panels*, respectively). Note that the *vertical axis* starts at 60%

Figure 3 suggests that the poorest performance arises when the spectacles shut before the catcher can obtain a reliable prediction of the ball's trajectory and only open again when there is no longer enough time to bring the hand to the ball on the basis of the new visual information. In both cases, we can expect the transition to be gradual. The early prediction gradually becomes better the longer the ball is visible before the spectacles close. The time needed to bring the hand to the ball when it reappears depends on how wrong the first estimate was, so having more time leads to a gradual improvement. We approximated the transitions by cumulative Gaussians and fit the combination of the two Gaussians to our measure of the quality of catching performance (Q_{catch}). We used the following general expression:

$$Q_{\mathrm{catch}} = \left(1 - \left(1 - G(t, \mu_p, \sigma_p)\right) \cdot G(t, \mu_c, \sigma_c)\right) \cdot Q_{\max} \qquad (1)$$

In this expression, t is the time at which the goggles open (or close; as will be explained below) and G represents a cumulative Gaussian function with mean μ and standard deviation σ. The subscripts p and c stand for early *prediction* and late *corrections*, respectively, and $Q_{\max}$ is the asymptotic performance with full vision. Based on the data, we estimated that $Q_{\max}$ is 0.95 (i.e. people do not always catch the ball perfectly with full vision). In Eq. 1, t is defined relative to the time of the experiment. We would like to know until how long before the catch new information can still be used to correct the catching movement, for which both t and μ_c must be related to the moment of the catch. We would also like to know how long from the moment the ball is released the ball must be seen for the prediction to be good enough for performing a high-quality catch, for which both t and μ_p must be related to the moment the ball is released. We therefore relate μ_c to when the spectacles open relative to the moment of the catch and μ_p to when the spectacles shut relative to the moment the ball is released. We define t differently for the two panels of Fig. 3, but μ_p and μ_p are defined in the same way for both panels, so for each panel, one of the means and standard deviations has to be converted. To do so, we have to consider the duration of the visual occlusion (t_o) and the mean flight time of the ball (t_f). For the right panel of Fig. 3 (in which time is defined relative to the catch), we replace Eq. 1 by:

$$Q_c = (1 - (1 - G(t, \mu_p + t_o - t_f, \sqrt{\sigma_p^2 + \sigma_f^2}))$$
$$\cdot G(t, \mu_c, \sigma_c)) \cdot Q_{\max} \qquad (2)$$

In this equation, time t is defined in terms of spectacle opening time relative to the time of the catch, which is appropriate for μ_c. Since μ_p is defined in terms of when the spectacles close relative to the ball being released, the mean of the Gaussian function for the prediction term is adjusted to $\mu_p + t_o - t_f$ for this equation; the spectacles open again 250 ms (t_o) after they close and on average, the ball is caught 483 ms after it is released (t_f). We account for the variability in the flight time of the ball by also considering this variability ($\sigma_f = 51$ ms) for the time that was not synchronized for the measure in question. Similarly, for the left panel of Fig. 3 (in which time is defined relative to release), we use:

$$Q_p = (1 - G(t, \mu_c - t_o + t_f, \sqrt{\sigma_c^2 + \sigma_f^2})$$
$$\cdot (1 - G(t, \mu_p, \sigma_p))) \cdot Q_{\max} \qquad (3)$$

In Eq. 3, the value of μ_c is adjusted in a similar manner to the way μ_p was adjusted in Eq. 2. We obtained estimates of the values of μ_p, μ_c, σ_p and σ_c by simultaneously fitting Eqs. 2 and 3 to the data points in the left and right panels of

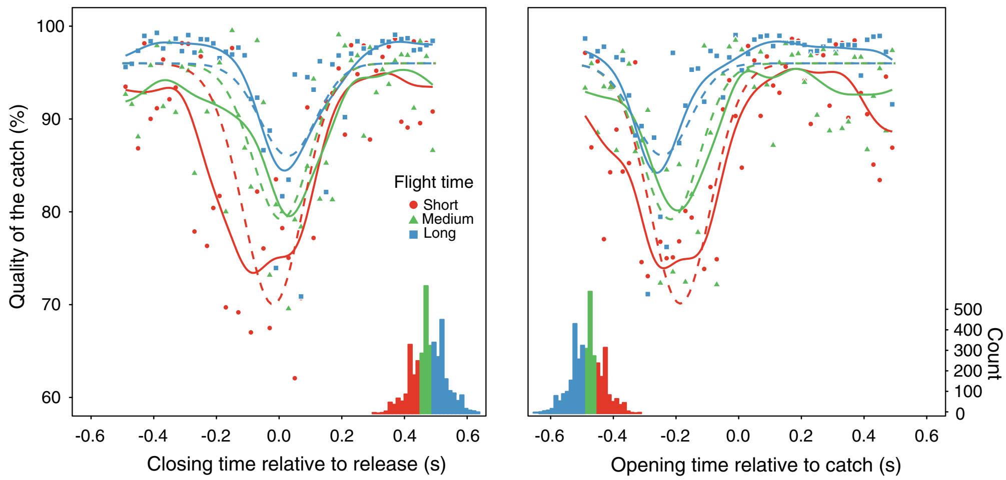

Fig. 4 Catching performance on trials with long (*blue*), medium (*green*) and short (*red*) flight times. The *solid curves* show smoothed versions of the data. The *dashed curves* show predictions based on Eqs. 2 and 3 (without changing any of the fit parameters). Other details as in Fig. 3. In the *bottom-right corner* of the *left panel* and the *bottom-left corner* of the *right panel*, we show the distribution of flight times in the three categories (*right axis*). In the former, this is the distribution of when the ball is caught (from the time it is released), and in the latter when the ball is released (relative to the catch) (colour figure online)

Fig. 3 (thick dashed lines; pooled values of all four subjects). The negative value of −5 ms for μ_p that we obtained from the fit means that it is enough to see the thrower's hand moving the ball until the moment of release for the quality of the catch to be halfway between the best performance and dropping the ball. Thus, the catcher can estimate the ball's trajectory quite reliably from the movement of the thrower's hand before the ball is released. The fit value of −186 ms for μ_c means that on average seeing the last 186 ms of the ball's flight is enough to ensure that the ball is caught well. The fit values of σ_p and σ_c are 99 and 111 ms. We also fit Eqs. 2 and 3 to the data of individual subjects. The values of μ_p varied between −5 and −17 ms. Those of μ_c varied between −165 and −212 ms. Thus, the critical times were quite consistent across subjects. The values of σ_p varied between 87 and 140 ms and those of σ_c varied between 94 and 153 ms.

Modelling the quality of performance with two independent Gaussians is obviously an over-simplification. Variability across trials in the ability to predict the ball's trajectory from the movement of the hand before release is likely to be independent of the ability to adjust the movement when new information becomes available, but the time needed to correct a movement depends on how far the hand is from the correct position, which in turn depends on the quality of the initial prediction, so the influences of the two factors on the quality of the catch are not really likely to be completely independent. To further validate the estimates of the critical moments that we determined from these equations, we considered that this view predicts that performance should be worse for trials in which the flight time was short. We can even predict how much worse. We split the catches into three groups on the basis of the flight times (irrespective of the participant). Figure 4 shows the quality of performance in the same format as Fig. 3, but split by flight time (long, medium and short). The flight time is longer when the ball is thrown higher or caught lower (or both). Participants did indeed perform better when the flight time was longer. The differences were globally consistent with predictions that we obtained from Eqs. 2 and 3 by simply changing the values of t_f and σ_f to their values after splitting the data (without any additional fitting; see dashed curves). The mean flight times for individual participants ranged from 444 to 529 ms, so part of the difference between participants (thin lines in Fig. 3) is due to differences in how the ball was thrown to and fro.

If our interpretation is correct, we expect to see most corrections to the final part of the hand movements when vision is restored at some moment during the first half of the ball's flight, and fewest corrections if vision is removed during that period. We use the standard deviation in the lateral velocity of the hand to quantify the magnitude of corrections. Figure 5a shows the average lateral velocity of the hand and its standard deviation during the ball's flight. Trials with full vision are shown in black. Trials in which vision was restored between 350 and 200 ms before the catch (so the first part of the ball's trajectory was hidden) are shown in green. Trials in which vision was occluded between 50 and 150 ms after release (so there was no time left for corrections when vision was restored) are shown in blue. Trials that did not fit into any of these categories are not represented in this Figure. It is evident from the standard deviations that people moved more differently across trials near the end of the movement (i.e. made more lateral adjustments) when they had to rely on information provided late in the ball's flight (solid green curve). The mean

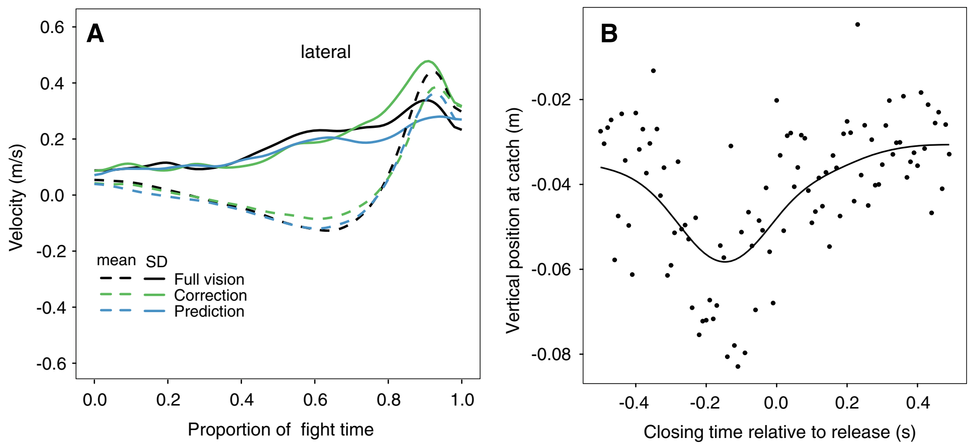

Fig. 5 **a** *Solid lines* show the standard deviation in the lateral velocity of the catcher's hand as a function of the time between the ball being released (time zero) and it being caught (time one). *Dashed lines* show the average lateral velocity of the hand, with positive values representing *rightward motion*. The visual information available to perform the catch is *colour-coded*: full vision in *black*, the spectacles opening just in time for a catch in *green* and the spectacles closing just after ball release in *blue*. The *curves* were smoothed by averaging all values within a moving time window of width 100 ms at each proportion of flight time (after removing evident outliers). **b** *Vertical position* of the catcher's hand, at the time of the catch, as a function of when the spectacles close relative to the time of release (zero denotes the spectacles closing exactly when the ball is released). The *curve* shows a smoothed version of the data (as in Fig. 3) (colour figure online)

lateral velocity traces were similar for all conditions (dashed curves).

The closing of the goggles was unpredictable, so subjects could not adjust their strategy in anticipation of this occurring. However, the goggles always opened 250 ms after closing, so when vision was occluded near the time at which the thrower released the ball, it was clear that vision would be restored late during the ball's flight. In such cases, the catcher could make a bit more time for adjusting the movement by catching the ball later. This would mean catching it lower, even if doing so is less comfortable. However, since the catcher knows in advance that he or she will be short of time, it is probably worthwhile aiming for a later and lower catch. Figure 5b shows the height of the hand at the moment of the catch as a function of when the spectacles closed relative to release of the ball. When vision was occluded while the thrower was propelling the ball, participants caught the ball lower. They presumably did so to increase the flight time after vision was restored so that there would be enough time to compensate for not having had enough information to plan the catch well in advance.

On average, the standard deviation in the position at which the ball was caught (within a session) was 8.1 cm laterally, 6.8 cm in height and 8.4 cm in depth. The lag-1 autocorrelation was neither significant for the lateral positions nor for the flight times. Thus, relying on information from the previous trial does not make catching the ball trivially simple. Nevertheless, it is evident that if the ball had been thrown less reproducibly, or faster, or if participants had been unable to anticipate the throw from the thrower's actions (as when a ball is dispensed from a machine), the catcher's performance would have been poorer, as it was in a pilot session that we conducted with a longer occlusion time. Conversely, if the ball had been thrown more regularly, the catchers' performance may have been even better. Jugglers are known to be able to catch balls with minimal visual information. Within sessions in our experiment, the standard deviations in the intervals between successive catches were between 0.5 and 0.7 s, which are about ten times larger than the variability in the flight times when juggling (van Santvoord and Beek 1996), and are longer than the flight times themselves. Thus, our results should be considered to represent catching performance under simple, but not trivially predictable, conditions.

Discussion

It was already well established that highly skilled athletes use information from before the ball is released to anticipate how it will be thrown (Müller et al. 2006; Müller and Abernethy 2006), but it was not yet clear whether this was only for predicting the kind of throw (for instance whether and how the ball would spin) or also for predicting the point of contact. We here show that at least for underarm throwing, information from before the ball is released is used to some extent to predict where it is going. We also confirm that information from just before the catch is used to guide the catch. Altogether these results confirm that people can pick up useful information at any time, only being limited by the resolution of such information and the delays involved in acquiring the information and transforming it into an appropriate action. We see no indication that a particular time is critical for successful catching other than the dependence that arises from the task itself. Note that although predicting the ball's trajectory and correcting judgment errors are separate components in the way we analyse the results, we do not consider these to be two fundamentally different processes. The distinction emerges because performance is only poorer when we block vision for some time between the time that the first prediction can be made and the last moment at which new visual information can lead to useful adjustments. Normally, people will continuously adjust their movements on the basis of continuously updated predictions (Smeets and Brenner 1995; Brenner and Smeets 2009).

Previous studies have often concentrated on very difficult conditions rather than the gently thrown balls of the present study. Obviously, very different issues arise when the thrower intentionally tries to throw the ball in such a way that it is difficult to predict its trajectory from that of the hand before the ball is released, or even from the ball's trajectory when one sees it flying, for instance by flipping the hand to spin the ball when it is released (Regan 1997). Similarly, the fact that experienced cricket batsmen focus on the bounce (Land and McLeod 2000) probably reflects the fact that that is when the most useful information is provided: accurate enough to determine where to hit and early enough to get there in time. Thus, the presence of a critical time window for picking up visual information does arise if the task dictates it, but we argue that this is not a general principle. The proposed flexibility in using information at any relevant time means that one must determine when visual information would be useful for any task that one studies. In tasks that require very precise timing of movement onset, seeing the target just before that moment may have a strong influence on performance, so there will in fact be a critical time (Tresilian and Houseman 2005; Lee et al. 1983). If the variability in the position of the catch is high one will have to see earlier parts of the trajectory because corrections will take longer. If the required accuracy is high, one will have to see later parts because the accuracy of predictions decreases with the time across which one must predict.

We did not vary the occlusion time. However, the variability in flight time across trials introduced variability in the relationship between the time for which the ball was visible in flight and the moment that vision was occluded relative to the moment of release. We used this to evaluate our interpretation. The fact that we could anticipate the effect of variations in flight time (Fig. 4) confirms that visual information rapidly becomes more informative near the time that the ball leaves the thrower's hand and rapidly becomes less useful about 200 ms before the catch. If the ball is visible for some time after it is released, or for more than 200 ms before the catch, catching performance is almost as good as if it is visible throughout. From our data, we cannot precisely estimate the value of seeing the thrower's moving hand at various times before the ball is released, but it is clear that seeing the ball's motion before it is released is far less effective than seeing it once it has left the hand. Vision of the thrower's hand provides an early estimate of the approximate time and place of the catch, which our catchers presumably used to decide when and how far to move their hand forward in anticipation of the ball's arrival, and when to start moving it back in order for it to be moving in the direction of the ball at the time of contact. The importance of seeing the release of the ball is that the time and place at which the ball can be caught is quite sensitive to the precise moment at which the ball is released. Thus, not seeing the release of the ball makes one have to rely on larger, late corrections. Larger corrections require more time and are therefore less likely to be successful.

In general, having more visual information is better, but the quality of the catch is a smooth and gradual function of the duration for which visual information is available. In underhand throwing, the moment at which the predictability of the ball's trajectory increases most rapidly, and therefore the time at which the quality of the catch is particularly sensitive to when exactly visual information is available, is when the ball is released. A second time at which the benefit of acquiring visual information changes particularly abruptly is when the ball is so near the catcher that there is no longer enough time for him or her to adjust his or her movements to reach an appropriate place at the same time the ball does. These transitions are not determined by the way in which catching movement are controlled, but by the fact that the accuracy of the information and the ability to use such information changes abruptly at these moments. Thus, people can catch a slowly thrown ball as long as the visual information is accurate enough to do so and is provided in time to bring the hand to a suitable position to do so.

Acknowledgments The first author was supported by grants SEJ2007-60488/PSIC and PR2007-0400 from the Ministry of Education and Science of the Spanish Government.

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