Catching of balls unexpectedly thrown and unexpectedly fired by cannon[1,2]

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Summary. – Although learned actions can be automatically elicited in response to expected stimuli for which they have been prepared, little is known about whether learned actions can be automatically initiated by unexpected stimuli. Responses of unwitting participants to balls unexpectedly thrown by an experimenter (n = 10) or propelled by a hidden ball cannon (n = 22) were recorded by motion capture. Experience of ball catching correlated negatively with hand movement distance, indicating most responses were defensive, but successful catches were made in response to both thrown and fired balls. Although reaction time was faster in response to fired balls, interception was more frequent in response to thrown balls, indicating that movement cues by the thrower facilitated unexpected ball catching. The latency to begin a catching action by the only successful catcher of an unexpectedly fired ball was 296 ms. Given current knowledge of reaction time tasks and latencies of neural substrates of conscious perception and deliberation, it is probable that there was insufficient time available for conscious preparation of catch attempts. Ball catching may represent an example of a learned response which can be rapidly and unconsciously initiated without contextual priming or expectation of the stimulus.

Unexpected ball catching is often raised in discussions of consciousness and intentionality as an example of behavior which is performed spontaneously "before deciding to do it" (Tallis, 2003; see also Banks, 2002; Bratman, 1987; Bumpus, 2001). That learned actions can be elicited rapidly and automatically, i.e. without involvement of consciousness in action initiation, has been reported in a variety of methodological paradigms (Dehaene et al., 1998; Herwig, Prinz, & Waszak, 2007; Hommel, 2007; Wegner, 2002). In studies of automatic reactions, however, generally participants expect that they might be required to react rapidly and with specific responses to specific stimuli. In such cases, a rapid automatic response is normally elicited as a “prepared reflex” (Hommel, 2000) which means that the action has been intentionally prepared to be an automatic response to an appropriate stimulus. Such stimuli occur in specific contexts – lights flash in a reaction time experiment; an errant pedestrian is seen by a driver; a ball is kicked towards a goalkeeper – and automatic responses are prepared to be ready in such contexts (Hommel, 2007). It appears, however, despite numerous anecdotes, there are no controlled studies of whether and how a learned response might be elicited automatically by a stimulus occurring outside its normal context.

Although ball catching is an intentionally trained and prepared response, individuals prepare the response for specific contexts such as ball games, not for contexts in which no balls are expected to be involved. Observation of automatic ball catching in a situation for which catching has not been prepared would have the implication that automatic stimulus responses prepared for a particular context can be on-line in other contexts. The observation would also have philosophical implications, because in contrast to the other mentioned examples of automatic action initiation, the subject would experience no intention to carry out the action prior to doing so.

Much is known about the functional mechanisms and neural substrates of interceptive behaviour (Davids, Savelsbergh, Bennett, & Kamp, 2002; Gray & Sieffert, 2005; McLeod, Reed, & Dienes, 2006; Regan, 1997; Tresilian, 2005; Zago, McIntyre, Senot, & Lacquaniti, 2009), including the effects of unexpected variation of trajectory (de Lussanet, Smeets, & Brenner, 2001; Gray, 2002), but until now there seems to have been no published study of catching unexpectedly thrown balls. The first aim of this study was therefore to provide exploratory description of the kinematics of responses to balls unexpectedly propelled towards participants under controlled conditions, with hand responses measured using a motion capture system. These responses were compared with responses to balls that participants expected and were instructed to attempt to catch. Exploratory analyses of the effects of individuals' past experience with ball catching on their responses to unexpected balls were also conducted.

The second aim of this study was to test the hypothesis that catching of unexpectedly thrown balls is facilitated by inadvertent signals by the thrower prior to ball-release (Williams & Starkes, 2002). Two conditions were therefore included: one in which a ball was unexpectedly thrown by a human experimenter, and one in which a ball was unexpectedly fired by a cannon of which the participants were unaware. In neither condition were there any clues prior to ball propulsion that balls or catching were involved in the experiment. This hypothesis predicts that interception would be more frequent when balls were thrown then fired.

Arms may be involuntarily raised defensively in response to an unexpected looming visual stimulus (King, Dykeman, Redgrave, & Dean, 1992). That such defensive movements would be observed was therefore predicted, although these were minimized by using a ball trajectory which was not on a collision course with participants. Catching and defensive arm raising have different origins, defensive arm raising being seen in nonhuman animals (Cooke & Graziano, 2003; King & Cowey, 1992) and newborns (implying the behaviour is not learnt, Ball & Tronick, 1971), whereas catching ballistic objects is not a universal human behavior and requires considerable practice to learn to perform successfully. The third aim of the study was to determine whether attempts to catch could be distinguished from defensive movements. It was hypothesized that catch attempts would be more likely to involve orientation of the palm towards the ball and finger extension, both of which are necessary for catching but potentially dangerous during defensive blocking as they expose more sensitive parts of the hand. Under the assumption that participants with more experience of catching are more likely to make attempts to catch, this hypothesis predicts that individuals with more experience of catching would be more likely to orient the hands and fingers in a manner conducive to catching.

The fourth aim of the study was to investigate the plausibility of the hypothesis that attempts to catch can be initiated in response to the appearance of an unexpected ball before there is time for a conscious reaction to the ball. Confirmation of this hypothesis would represent demonstration of the so far unknown phenomenon of an automatic learnt response occurring outside of the context for which it was prepared. Observed latencies of attempts to catch are therefore discussed in light of what is known about latencies of neural and cognitive processes associated with consciousness and decision making.

Method

Participants

Included in analysis were thirty-eight participants (15 males) who were students (mean age = 24.6 years, *SD* = 3.0) who volunteered by signing up on notice boards in the department and who were assigned randomly to conditions, and an additional five participants (three males) who were volunteers (mean age = 22.8 years, *SD* = 4.5) recruited directly from sports clubs and who were all assigned to the condition in which balls were fired by cannon (see below). A further seven participants were tested but excluded from analysis because the ball cannon misfired (three), because the motion capture system failed (three), and because of inattention (one).

Materials

Kinematics of ball and participant were captured at 240 Hz with a motion capture system (ProReflex, Qualisys, Gothenburg, Sweden) for tracking infrared reflective markers. The ball was of orange soft foam rubber, tennis-ball sized (7 cm diameter), and encircled by white infrared-reflective fabric tape to enable motion capture. Digital video footage was captured at 15 Hz.

The custom-constructed cannon propelled the ball by release of compressed air. The cannon was hidden from the participant behind a black hanging cloth with a ball-sized hole at 1.5 m height. Through the hole could be seen only another black cloth. On firing there was an audible (L_A = 80 dB) 2-s hiss, beginning a mean of 111 ms (*SD* = 18) before the ball became visible to the participant. Because the sporting clubs of which participants were members did not use ball cannons, and because our ball cannon made a different type of noise to commercially available ball cannons as it was custom constructed to fire very soft balls, there is very little reason to believe the hiss would prime catching.

The cannon fired so the ball fell in between a participant’s feet, necessitating a forward reach to catch, and making ‘accidental’ catching impossible, although due to minor variation in trajectory the ball sometimes struck a participant’s legs. Occasional misfires caused the ball to fall too short to catch; such trials were excluded (see above).

Design

Each participant took part in one condition only: fired ball, thrown ball, or hiss control. In all conditions, the participant was first exposed to an unexpected event trial, and then the same event was repeated twice in two expected event trials. In the fired-ball condition (n = 22) a ball was fired from the cannon at the participant. In the thrown-ball condition (n = 10) a concealed ball was thrown by the experimenter at the participant. In the hiss-control condition (n = 11) a ball was fired by the cannon, producing a sound identical to in the fired-ball condition, but the ball was trapped before passing the black cloth so did not become visible to the participant. This condition was intended to record reaction attributable to the hiss sound alone.

Procedure

Prior to the experiment participants were given practical information such as approximate study length, but no information on the procedure except the study concerned “the connection between motor behavior and cognition” and that “a simple motor task” would be performed and recorded. After entering the laboratory, the participant read and signed a consent form containing this information. A marker was positioned on each shoulder and knee, and, for each hand, on the thumb metacarpal and on the ulna-carpus junction. The analysis focused on hand movements: the other markers were used only to distract participants from perceiving this.

Each participant was positioned standing with toes on a line 2.5 m from the hanging black cloth and ask to stand with arms hanging freely. In the thrown-ball condition the experimenter positioned himself in front of the cloth, which had been moved backwards 50 cm to allow the ball to appear at about the same location as the fired ball. In the other conditions the experimenter remained in view but sat at a side table. Participants in the fired-ball and hiss-control conditions were then told: “Please look at me. I’m now going to show you some stimuli, in other words, things in the hole. Then later I’m going to measure some movements you’re going to carry out. First is a training phase. Okay, now you can look in the hole.” Participants in the thrown-ball condition were instead told “Please look at me. I’m now going to show you some stimuli, in other words, things. Then later I’m going to measure some movements you’re going to carry out. First is a training phase. Okay, now you can look at me.”

The unexpected event trial was then begun. In the fired-ball and hiss-control conditions, the cannon was triggered by a key press by the experimenter which caused firing after a random delay of one to seven seconds. In the thrown-ball condition, the ball (which had been concealed in the experimenter's hand) was thrown instead by the experimenter in a trajectory intended to mimic that of cannon fired-balls. Participants were then informed there would be two further trials which would be the same as the first trial. No further instruction was given except a request the participants attempt to catch the ball.

After all three trials, the participant completed a questionnaire concerning sporting experience. We report data from three items here: firstly a four-point ordinal scale item assessing frequency of ball catching in normal life, secondly a four-point Likert item "I have played a lot of ball sports", and thirdly an open ended question requesting details of any sporting activities carried out at club level. Local ethical review procedures were adhered to in carrying out this study.

Calculation and coding of kinematic summary variables

The following variables were calculated separately for each hand. *Displacement* was the distance measured from the location of the hand at the moment the ball appeared to the location of the hand at the moment of catching, or to the farthest location the hand reached in 1 s after the ball appeared if catching did not occur. *Divergence* represented to what extent the hand moved in a direction appropriate for ball interception, with an appropriate direction indicated by low divergence. Before defining divergence we must define the *typical catching location* as the mean hand location for all catches made in trials when a ball was expected to be fired. Divergence was the angle between two vectors, (1) from the hand location at the moment the ball appeared to the typical catching location, and (2) from the hand location at the moment the ball appeared to the location at which hand displacement is measured. That low divergence values indicated hand movement appropriate for interception was confirmed by the observation that the mean divergence on trials when a fired ball was expected was 16º (SD = 9º).

For trials on which a ball was unexpectedly fired, two hand posture variables, *palm presentation* and *finger extension*, were coded by observations of video recordings. Video data are missing for five of 22 participants due to technical problems so all analyses of these two variables were restricted to 17 participants. These were binary presence or absence variables and there was 100% inter-observer agreement for two independent coders who were an undergraduate student and an experienced researcher. Finger extension was scored if the coder observed any increase in finger extension during the response period (although not instructed to, all participants began using a relaxed hand position with fingers neither clenched nor fully extended). Palm presentation was scored if rotation of the palm towards the ball was judged to be sufficient for ball-palm contact if interception was to occur (no participants began with palms so oriented).

Two types of reaction time were calculated for each hand: *latency to first reaction*, and *latency to hand orientation*. Calculating these two latencies allows taking into account the possibility that although hand orientation may mark the onset of an attempt to catch, it may be preceded by an earlier response which is purely defensive. The latency to first reaction was determined as follows. The maximum scalar acceleration was calculated for the hand in the 1 s baseline period before ball appearance (when hands were normally still), and the first time after the ball became visible that the hand's scalar acceleration exceeded this maximum baseline value was taken as the moment of reaction. The latency to hand orientation was defined as the first video frame in which rotation of either hand was clearly visible. Note that given the video frame rate, the coded latency to hand orientation could have been up to 67ms later than the actual latency (though not earlier, so this measure is conservative). Hand rotation was not reliably codable from motion capture data because one of the two hand markers was often obscured.

Statistical analysis

Comparison of responses to expected and unexpected balls is simpler with one trial of each type per participant, so of the two expected-ball trials for each participant, only the first valid trial was included in analysis. The second expected-ball trial was therefore only included on three occasions in which technical failures invalidated the first but not the second expected-ball trial. Two participants contributed unexpected-ball trials but no expected ball trials, due to equipment failure and experimenter error respectively. These individuals are included in analyses focusing only on unexpected-ball trials, but not in analysis comparing expected and unexpected-ball trials.

Exploratory analyses of kinematic variables examining effects of propulsion method and effects of whether or not the ball was expected were conducted using general linear models with type III sums of squares, entering as fixed factors propulsion method (fired or thrown), trial type (expected or unexpected ball), the interaction, and as a random factor individual nested in propulsion method (including individual as a random factor allows valid modelling of the within-subject aspect of the design, Grafen & Hails, 2002). Post-hoc *t*-tests examined the effects of propulsion method separately for expected and unexpected-ball trials. Exploratory analyses of the relations between kinematic variables and between kinematic variables and experience of ball catching in normal life were conducted using simple linear regressions. Parametric model fits were confirmed as acceptable (by inspecting diagnostic scatter plots of standardized residuals, Grafen & Hails, 2002) once latency to first reaction and divergence had been log transformed and hand displacement had been square root transformed. All *t*-tests assumed unequal variance and all statistical tests were two-tailed.

Results

Interception frequencies of expected and unexpected fired and thrown balls

Of the 22 participants in the fired-ball condition, one caught the unexpected ball (Supplementary Video 1a), and one made a fumble (contacting the ball in flight with a hand but without catching, Supplementary Video 1b). [**NOTE**: the supplementary videos are available at: http://www.youtube.com/user/unexpectedball#p/u]. Neither participant had been recruited directly from a ball-sport club. The remaining 20 participants in the fired-ball condition did not contact the unexpected ball with their hands. In contrast, all participants in the fired-ball condition caught the expected ball, except for one participant who fumbled it. All participants reported that nothing prior to the unexpected ball appearance had led them to expect a ball or other projectile.

Of the ten participants in the thrown-ball condition, two caught and four fumbled the unexpected ball, and all caught the expected ball. Interception (catching or fumbling) was therefore more frequent in response to unexpected thrown balls than to unexpected fired balls, $p = .005$, Fisher’s exact test, relative risk = 6.6. This was unlikely to be because thrown balls were easier to catch than fired balls – thrown balls, with mean speed 4.5 ms^{-1}, were not slower than fired balls, with mean speed 3.8 ms^{-1}, $t(9) = 1.49$, $p = 0.170$. Although thrown balls were more variable, $SD = 1.4$ ms^{-1} compared to 0.2 ms^{-1}, even balls thrown faster than the mean fired speed were more likely to be intercepted (three of five) than all balls in the fired-ball condition, $p = .030$, Fisher’s exact test, relative risk = 6.6. Mean air time of unexpected fired balls (time from appearance to passing the typical catching location) was 0.64 s ($SD = 0.03$).

Kinematics of responses to expected and unexpected fired and thrown balls

Because each reported catch (including those made in response to unexpected balls) was made using both hands simultaneously, and because preliminary analyses showed no significant differences in values for the two hands, all reported values for all variables are the means within each trial of the left and right hand values. The only exceptions are the reaction latency variables, for which we report the earliest reaction of either hand.

All 22 participants in the fired-ball condition and all ten participants in the thrown-ball condition reacted to the unexpected ball by initiating hand movements of considerable mean speed, whereas participants in the hiss-control condition performed virtually no movement (Figure 1). The hiss-control condition therefore fulfilled its purpose in demonstrating that very little movement can be attributed to a reaction to the hiss sound alone and is not considered further.

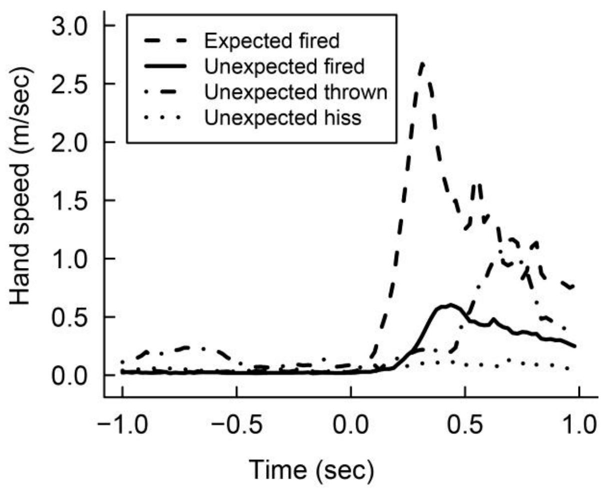

Figure 1. Mean hand speeds in response to unexpectedly thrown and fired balls, unexpected hiss, and expected fired balls, before and after the ball’s appearance. For the hiss control, time zero is the moment when the ball would have become visible had it not been stopped before appearance. Individuals’ speeds were smoothed using a five-frame (21 ms) window simple moving average.

Table 1.

Models of Hand Displacement and Latency to First Reaction with Ball Expected or Unexpected as One Factor and Ball Fired or Thrown as Another Factor

Factors	*d.f.*	*F*	*p*	η^2
		Hand displacement		
Ball expected or unexpected	1,28	87.05	< 0.001	0.61
Ball fired or thrown	1,28	2.70	0.110	0.02
Interaction	1,28	5.06	0.033	0.03
		Latency to first reaction		
Ball expected or unexpected	1,28	54.68	< 0.001	0.46
Ball fired or thrown	1,28	0.33	0.567	0.01
Interaction	1,28	3.80	0.061	0.04

Note. Models are general linear mixed models with ball expected or unexpected as a fixed factor, ball fired or thrown as a fixed factor, the interaction between the two fixed factors, and, to allow the within individual design, individual as a random factor nested in ball fired or thrown.

Hand displacement was significantly greater in response to expected than to unexpected balls (Figure 2, Table 1). There was no main effect of propulsion method on displacement, but its interaction with whether or not the ball was expected was significant. This interaction reflected the observation that while displacement was marginally significantly greater in response to unexpectedly thrown balls than to unexpectedly fired balls, $t(13) = 2.04$, $p = 0.062$, $d = 0.91$, there was no difference in displacement in response to expectedly thrown balls and expectedly fired balls, $t(13) = 0.45$, $p = 0.659$, (Figure 1, Table 1). Note that divergence cannot sensibly be compared between propulsion methods because the typical catching location for fired balls is not necessarily an appropriate catching location for thrown balls, due to their much higher variation in trajectory.

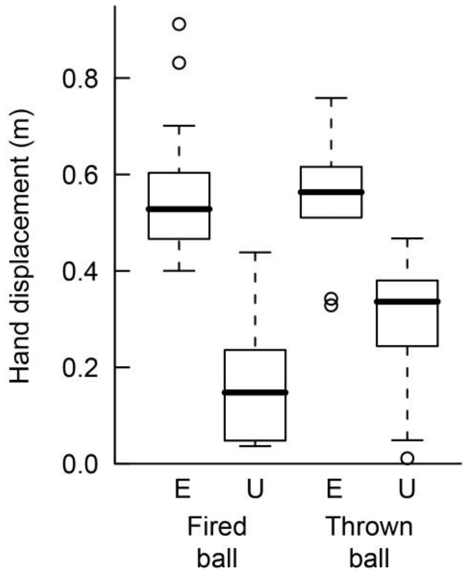

Fig. 2. Boxplots of hand displacement in response to expected (E) and unexpected (U) fired and thrown balls.

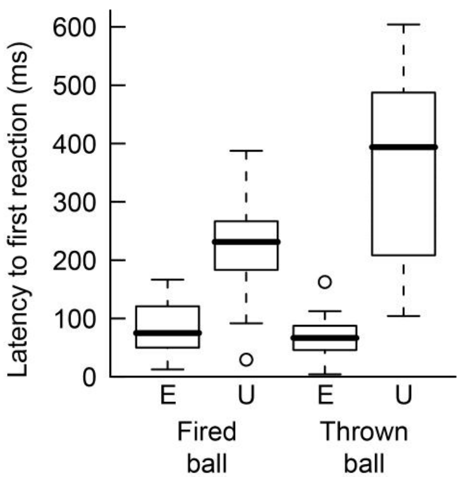

Fig. 3. Boxplots of latency to first reaction in response to expected (E) and unexpected (U) fired and thrown balls.

Latency to first reaction was shorter in response to expected balls than to unexpected balls (Figure 3, Table 1). There was no main effect of propulsion method on latency to first reaction, but its interaction with whether or not the ball was expected was marginally significant. This interaction reflected the observation that while latency to first reaction was significantly shorter in response to unexpectedly fired balls than to unexpectedly thrown balls, $t(16) = 2.35$, $p = 0.032$, $d = 0.94$, there was no difference in latency to first reaction in response to expectedly thrown balls and expectedly fired balls, $t(10) = 0.74$, $p = 0.475$ (Figure 3, Table 1).

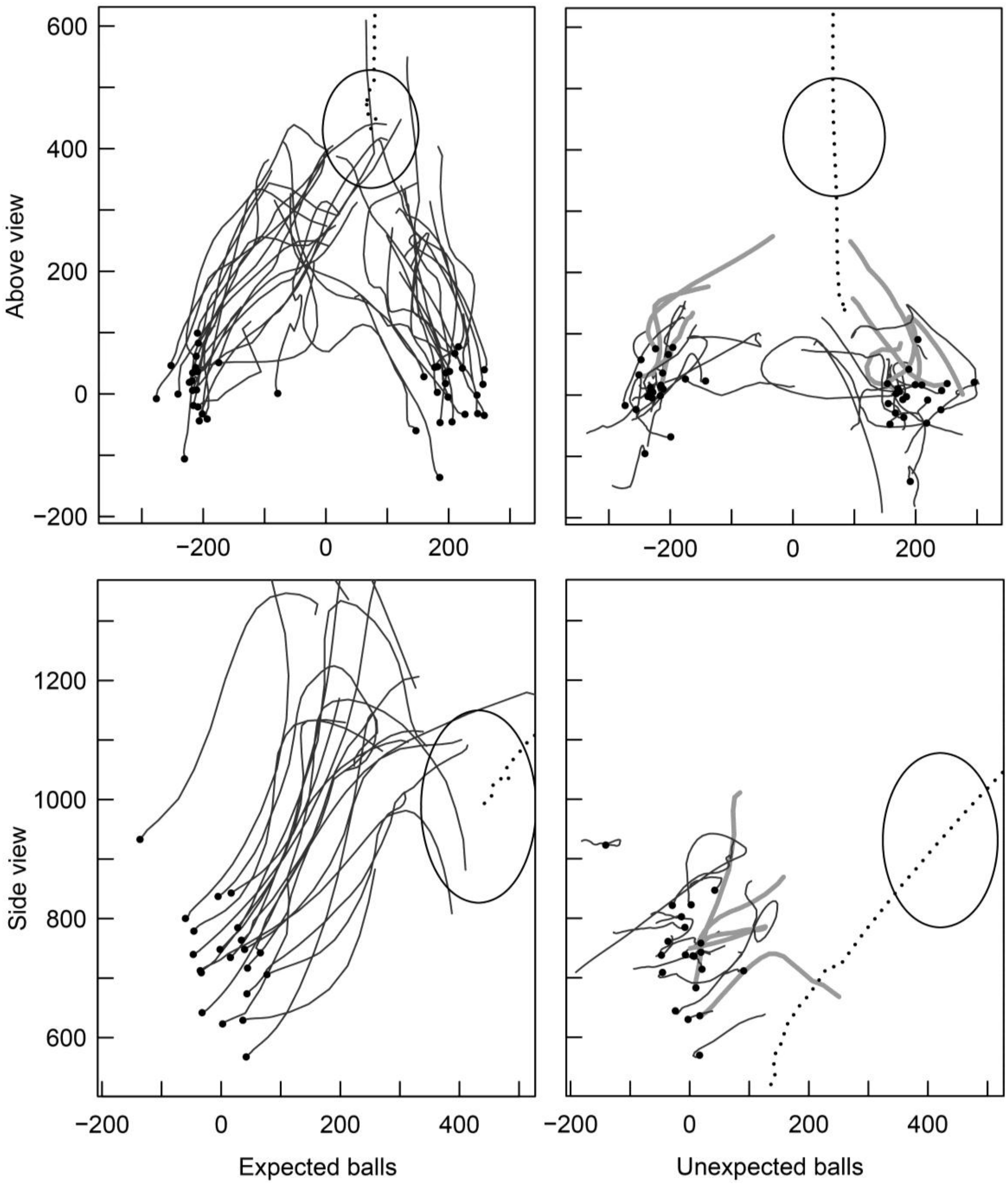

Fig. 4. Hand trajectories in responses to fired balls, with both hands as seen from above and with the right hand only as seen from the side. Dots show start positions. Thick grey lines show trajectories in which hands were oriented to enable catching (hand orientors). The dotted line shows the mean ball trajectory, with the error oval showing standard deviation at mean time point of catching. Coordinates are millimetres from the origin, which is on the floor equidistant between the front of the feet. Gaps in hand trajectories due to obscuration of the marker have been spline interpolated. On expected ball trials, when the ball was

normally caught, the reasons hands do not converge exactly onto the ball's trajectory are threefold: hand markers were positioned on the base of the hand; the moment of catching was usually when the ball contacted the ends of fingers; and given position of the cameras, the motion capture system detected the ball's distal edge rather than its center.

Individuals differences in response to unexpectedly fired balls

The rest of the analysis concerns only reactions to unexpectedly fired balls as this is the data most relevant to the issue of automatic reactions to unexpected events. Hand movement direction was greatly variable (Figure 4) but more often than not brought the hand closer to the typical catching location – the mean divergence of 76º (*SD* = 47º) was less than 90º, $t(21) = 2.49$, $p = .021$, $d = 0.30$. Visual inspection of hand trajectories suggests a further general pattern: some participants moved their hands a considerable distance towards the typical catching location, whereas others moved their hands a shorter distance and without a bias towards the typical catching location. This observation is confirmed by the presence of a negative correlation between divergence and hand displacement, $F(1,20) = 13.68$, $p = .001$, $R^2 = 0.41$.

Lower reported ball catching frequencies in normal life predicted a greater hand displacement, $F(1,20) = 13.30$, $p = .002$, $R^2 = 0.40$, and a lesser divergence, $F(1,20) = 12.15$, $p = .002$, $R^2 = 0.38$. As a measure of effect size, individuals reporting they caught balls more than once a week had a mean hand displacement of 6.1 cm (*SD* = 2.6, *n* = 7), whereas the mean hand displacement for those reporting they caught balls less than once a month was 21.3 cm (*SD* = 13.6, *n* = 7).

Of the 17 of 22 participants for whom video coding was possible, finger extension and presentation of the palm towards the ball were both used by four participants (Supplementary Videos 1a to 1d). These participants are hereafter referred to as hand orientors. No other participants used finger extension or palm presentation. For purposes of comparison with the hand orientors, Supplementary Videos 2a to 2d show the four non-hand-orientors who had the most closely matched hand displacements to the hand orientors. Latencies to hand orientation for the four hand orientors were 279 ms, 296 ms (catcher), 304 ms (fumbler), and 587 ms.

The only two participants who reported experience playing as goalkeeper in ball sports were both hand orientors. One was the catcher, who reported goalkeeping experience in four different ball sports. This means that hand orientors were more likely to be goalkeepers than non-hand-orienteers were, $p = .044$, Fisher's exact test, relative risk = 7.5. Hand orientors did not report a significantly higher frequency of ball catching in normal life than non-hand orientors, $t(5) = 0.38$, $p = 0.721$, but they were more likely to agree with the statement "I have played a lot of ball sports" – all four agreed, whereas only four of 13 non-hand orientors did, $p = 0.029$, Fisher's exact test, relative risk = 3.2.

Discussion

Factors determining probability of interception of unexpected balls

It was demonstrated that it is indeed possible to catch a ball unexpectedly propelled from a short distance. It is even possible when there are no movement cues available from a human thrower. However, unexpectedly thrown balls were intercepted 6.6 times more frequently than unexpectedly fired balls, giving support to the hypothesis that thrown balls are easier to intercept because of body movement cues given by the thrower immediately prior to ball release (Williams & Starkes, 2002). In the fired-ball condition, although the situation is likely to have generally primed the motor system and raised alertness levels above average levels outside the experimental situation, there were no cues that could have specifically primed the action of ball catching.

The observation that unexpectedly thrown balls were more frequently intercepted than unexpectedly fired balls is reflected by the observation that hands moved further in response to unexpectedly thrown balls. However, a somewhat less obvious effect was the observation that the latency to first reaction was shorter in response to unexpectedly fired balls, although interception was less frequent. This observation can be tied to the observation that accurate ball interception by sports players is predicted not by reaction time, but by quality of reaction (McLeod, 1987). It is likely that the more complex stimulus of a human throwing a ball required more time to process and react to than a looming ball on its own, but once processed the stimulus of a human thrower facilitated interception. The very low latencies to first reaction in response to expected balls indicate that in the thrown-ball condition, participants were responding to the thrower's movement cues, and in the fired-ball condition, participants had learnt from the prior unexpected ball that the hiss predicted the ball.

Attempts to catch and defensive blocking of unexpectedly fired balls

Our exploratory analyses showed that in response to unexpected fired balls, most hands moved either a relatively long distance and towards the ball, or a shorter distance which was less directed towards the ball. A relatively high frequency of ball catching in normal life predicted the latter pattern of a relatively small amount of undirected movement. A minority of participants, referred to as hand orientors, distinguished themselves by orienting their palms towards the ball, and by extending their fingers. These participants had greater experience with ball sports than the other participants.

These patterns of responses to unexpectedly fired balls are readily compatible with our hypothesis that both defensive movements and catching attempts would be observed. According to this hypothesis, hand orientors moved their hands towards the ball to attempt catches (Supplementary Videos 1a to 1d), and non-hand orientors who moved their hands towards the ball (Supplementary Videos 2a to 2d) did so defensively (Cooke & Graziano, 2003; King, et al., 1992). Greater experience with catching may be associated with perception of an approaching ball as less alarming, so fewer defensive movements appear, which could explain the negative correlation between catching experience and hand displacement. Although it cannot be ruled out that even the hand-orientation movements were defensive rather than attempts to catch, this seems unlikely in light of several observations. Firstly, hand orientors were more likely than non-hand orientors to have experience of goalkeeping. Secondly, they were more likely to have played a lot of ball sports. Thirdly, one individual’s hand orientation resulted in a successful catch.

The possibility of unconscious initiation of attempts to catch unexpected balls

This discussion is based on the four hand orientors’ observed latencies to hand orientation (279, 296, 304, and 587 ms), which are the earliest time points for which there is evidence the movements were attempts to catch rather than being purely defensive. Typical reaction times in standard reaction time tasks depend on the nature of the task. In simple reaction tasks, when only one stimulus with one appropriate response is included, reaction times are frequently below 200 ms (Brebner & Welford, 1980). Such tasks are much less demanding than the present one, however, because they require neither stimulus identification nor selection of action (Miller & Low, 2001). Median reaction times for visual discrimination choice tasks, which include more than one stimulus and response type, tend to be around 400 ms, and minimum reaction times are seldom below 300 ms (Smith & Ratcliff, 2004). The choice task which appears to be the simplest known (Jensen & Munro, 1979) produced a median reaction time for participants with similar ages and backgrounds to ours after considerable practice of 313 ms (Bates & Stough, 1998).

The latencies to hand orientation observed here may therefore be equivalent to or slightly faster than median latencies in an undemanding visual discrimination choice task. There are many ways in which our task differs from such tasks, but they at least share the properties that stimulus identification must be made followed by appropriate selection and initiation of action. Importantly, in standard visual discrimination choice tasks responses are consciously prepared in anticipation of an expected stimulus, and then executed automatically (Dehaene, et al., 1998; Herwig, et al., 2007; Hommel, 2000; Jeannerod, 2006). It is unlikely that a further processing stage comprising conscious deliberation of an appropriate response to the unexpected ball could take place in this task without prolonging the action latency beyond that which is normal for such standard tasks. A conclusion compatible with the latencies to hand orientation observed here is therefore that the visual stimulus of a looming ball can sometimes automatically elicit the associated motor response of a catching attempt without the response having been consciously prepared for the specific context.

Data regarding typical latencies of the neural correlates of conscious perception and deliberation is also relevant. Unfortunately there is no consensus as to the delay between visual stimulation and conscious perception (Fahrenfort, Scholte, & Lamme, 2008; Gaillard et al., 2009; Pins & ffytche, 2003). It is not disputed, however, that the basis of conscious deliberation is sustained frontoparietal activity (Brass & Haggard, 2007; Kuo, Sjöström, Chen, Wang, & Huang, 2009). In visual discrimination tasks such activity begins at around 270 to 300 ms (Gaillard, et al., 2009; Sergent, Baillet, & Dehaene, 2005). As neural activity was not measured here, it is not certain that these timings are directly relevant to the present situation, but it has been argued that the specific form of a visual stimulus should not affect the latency of conscious processing (Gaillard, et al., 2009). If participants here showed similar latencies to conscious deliberation as was previously reported (Gaillard, et al., 2009; Sergent, et al., 2005), then hand orientation began approximately simultaneous with conscious deliberation of the stimulus. This would preclude conscious preparation of the response, as more time would have been required for deliberation and subsequent initiation of a motor response (Miller & Low, 2001; Zago, et al., 2009).

In summary, comparisons of the latencies to hand orientation with latencies observed in other reaction time experiments and in neuroimaging experiments indicate the data are compatible with the hypothesis that attempts to catch balls were initiated unconsciously, even though balls were not expected in this context. Support for the hypothesis is weak because of the small sample size of catch attempts, the debatable classification of catching attempts, and because the compared latency data are from situations which may not be entirely compatible. A more definitive test of this hypothesis will require further work. This hypothesis is of interest because if true, it would mean that automatic unconscious initiation of learnt action is not limited to situations in which action has been specifically primed (Bargh & Chartrand, 1999) or prepared in expectation of the stimulus (Haggard, 2005; Libet, 1985; Soon, Brass, Heinze, & Haynes, 2008). It is finally noted, however, on the basis of the observation that only those participants with much experience of ball sports made movements appearing to be attempts to catch, that such automatic responses to unexpected stimuli might only occur if highly trained.

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