Exp Brain Res (2007) 179:723–726
DOI 10.1007/s00221-007-0957-5

RESEARCH NOTE

Stereo vision enhances the learning of a catching skill

Liesbeth I. N. Mazyn · Matthieu Lenoir · Gilles Montagne · Christophe Delaey · Geert J. P. Savelsbergh

Received: 12 April 2006 / Accepted: 12 April 2007 / Published online: 9 May 2007

Abstract The aim of this study was to investigate the contribution of stereo vision to the acquisition of a natural interception task. Poor catchers with good ($N = 8$; Stereo+) and weak ($N = 6$; Stereo−) stereo vision participated in an intensive training program spread over 2 weeks, during which they caught over 1,400 tennis balls in a pre-post-retention design. While the Stereo+ group improved from a catching percentage of 18% to 59%, catchers in the Stereo− group did not significantly improve (from 10 to 31%), this progress being indifferent from a control group ($N = 9$) that did not practice at all. These results indicate that the development and use of of compensatory cues for depth perception in people with weak stereopsis is insufficient to successfully deal with interceptions under high temporal constraints, and that this disadvantage cannot be fully attenuated by specific and intensive training.

L. I. N. Mazyn (✉) · M. Lenoir
Department of Movement and Sports Sciences,
Ghent University, Watersportlaan 2, 9000 Gent, Belgium
e-mail: Matthieu.Lenoir@ugent.be

G. Montagne
Faculté des Sciences du Sport, Université de la Méditerranée,
Marseille, France

C. Delaey
Department of General Physiology,
Human Physiology and Pathophysiology,
Ghent University, Gent, Belgium

G. J. P. Savelsbergh
Faculty of Human Movement Sciences,
Free University Amsterdam, Amsterdam, The Netherlands

G. J. P. Savelsbergh
Department of Exercise and Sport Sciences,
Manchester Metropolitan University, Manchester, UK

Keywords Stereo vision · Motor learning · Catching · Visual information

Introduction

The ability to fuse images from both eyes allows an accurate perception of the surrounding world in three dimensions. Stereo vision is one of the numerous potential information sources for accurate perception of objects in depth, and becomes increasingly important when the object approaches in one's action space (Cutting and Vishton 1995). While the mechanisms of stereopsis are well known today (e.g. Collewijn and Erkelens 1990), its functional significance has, quite surprisingly, been given much less attention. The question whether stereo vision is essential in daily activities has only been scarcely documented so far. Much attention has been paid to which cues are most helpful in judging egocentric distance and distance between objects, mostly in static conditions (Cutting and Vishton 1995). However, stereo vision might support activities such as participation in ball sports or safe behaviour in temporally constrained traffic situations. With regard to traffic behaviour, Bauer et al. (2000) found that, in situations of limited car velocities and/or liberal time constraints, a lack of stereo vision was not detrimental to drivers' performance. Several other studies did not find adverse effects of a diminished stereo vision on the quality of life in general (Kuang et al. 2005).

From these studies, and some anecdotal evidence of elite performances by one-eyed athletes or pilots (see Fielder and Moseley 1996; Regan 1997), it seems that a lack of stereopsis does not hamper adequate interaction with our environment. It has often been argued that people with a congenital or early onset lack of stereopsis develop compensatory strategies that enable them to circumvent this visual deficit. Such strategies include the use of monocular cues like occlusion, accommodation, and motion parallax (Patterson and Wayne 1992; Cutting and Vishton 1995). From studies with a monocular—binocular paradigm (e.g. Savelsberhg and Whiting 1992) we know that information from one eye is sufficient to learn to catch a ball with one hand if extensive training is provided. Ball catching involves accurate perception and anticipation of spatial as well as temporal aspects of the ball-hand contact, i.e. when and where exactly the ball will arrive. However, monocular conditions are not tantamount to a non-stereopsis condition, which necessitates a cautious interpretation of these results.[1] In addition, Lenoir et al. (1999) and Mazyn et al. (2004) did not find evidence for successful compensatory strategies in catchers with a congenital or early onset lack of stereopsis. They showed that a lack of stereo vision is associated with a decrease in unimanual catching performance. Since stereo vision might contribute to the perception of depth in this task, it could provide the catcher with temporal as well as spatial information. In the Mazyn et al. (2004) study, participants with good stereopsis had higher success rates as compared to the participants with a significant lack of stereo vision (92 versus 75% successful catches). More specifically, the advantage of having good stereopsis increased with increasing velocity of the ball: at a ball speed of 14.6 m/s, participants with good stereopsis scored 83%, while catchers with low stereopsis hardly caught one ball out of two (54%). At a low ball speed of 8.4 m/s, this difference was much less pronounced (99 vs. 91%).

Given these differences, it is of importance to elucidate to what extent extensive training can compensate for a lack of stereo vision in situations of high temporal constraints like sports and traffic. In this study, we focus on one-handed ball catching, a task that is featured by high temporal constraints and a reliance on—amongst others—stereo vision (Mazyn et al. 2004). If stereopsis entails essential information for accurate catching performance that cannot be substituted by other informational cues, it is expected that catchers with low stereo vision will only make a limited, if any, progress during the learning period.

[1] There is a wealth of indirect evidence for the use of stereo vision in interceptive behaviour from studies with a monocular/binocular paradigm or from studies using a telestereoscope or virtual reality (Rushton and Wann 1999; Judge and Bradford 1988; van der Kamp et al. 1999). However, covering one eye implies the loss of more than stereo vision alone since concordant information is also absent. In addition, most of these studies use healthy participants for whom a particular visual condition is a new and unusual situation, which makes comparison with the behaviour of people with an early onset lack of stereopsis problematic. For an elaboration of these arguments, see Lenoir et al. (1999) and Mazyn et al. (2004).

Methods

Participants

Twenty-three female participants (22.2 ± 4.4 years of age) with visual acuity of 1.00 participated in this experiment. They were recruited from a database of approximately 400 subjects between 18–30 years of whom stereo vision was evaluated by means of the Graded Circles Test (Stereo Optical Company Inc., Chicago). These tests were conducted at the Department of Ophthalmology of the Ghent University. All participants were considered as poor catchers given their catching performance of less than 50% at a ball speed of 10.8 m/s as established in selection tests. Eight subjects had normal stereopsis (stereo acuity of less than 40 s of arc; Fielder and Moseley 1996) and were assigned to the Stereo+ group. Six subjects with a significant lack of stereopsis (more than 400 s of arc) formed the Stereo− group. Finally, nine subjects with good stereopsis (less than 40 s of arc) served as a control group and received no training. Participants were naive to the hypothesis of the experiment and were paid a small fee for their collaboration. The study was approved by the ethics committee of the Ghent University Hospital.

Apparatus and task

Yellow mid-pressure tennis balls were launched towards the participants with a ball-projection machine (Promatch/Mubo BV, Gorinchem, The Netherlands) from a distance of 8.40 m at a velocity of 13 m/s (resulting in flight times of ±645 ms to reach the participants' frontal plane). Balls arrived within an imaginary circle with its centre approximately 15 cm above the catcher's shoulder. Participants stood upright with their catching hand near the thigh, in a natural relaxed position. All trials were recorded with a Logitec Quick Cam Pro 4000 webcam (30 Hz) from the medial side of the catching arm.

Procedure

Participants in the Stereo+ and Stereo− group followed an intensive training program consisting of eight sessions of 180 catches at a ball speed of 13 m/s, spread over 2 weeks. Balls were presented in blocks of 30 trials, separated by a 5-min rest period. In a pretest, posttest, and retention test 2 months later, one set of 30 trials was performed at the same ball speed, and one set at a speed higher (15.0 m/s; flight time of ±565 ms) and lower (10.8 m/s; flight time of ±775 ms) than the training speed in order to assess potential transfer effects. Each trial was scored as a catch or a miss.

Table 1 Means and SDs of catching performance in %

	Pretest						Posttest						Retention					
	Low		Medium		High		Low		Medium		High		Low		Medium		High	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Control	28.5	15.7	13.3	10.8	6.3	5.9	36.3	15.8	16.7	11.3	5.9	8.0	42.2	22.0	20.4	14.6	7.4	7.7
Stereo+	36.3	17.5	12.9	11.3	5.0	6.4	68.8	16.3	69.7	17.0	37.5	24.4	65.0	34.4	65.8	19.3	34.2	20.1
Stereo−	17.8	11.9	10.0	16.0	1.7	4.1	40.6	33.0	28.3	32.3	25.0	31.3	50.0	35.3	32.8	21.0	23.9	30.8

Data analysis

The percentage of successful catches was analyzed by means of a 3 (Groups: Control, Stereo+, and Stereo−) × 3 (Time: pre, post, and retention) × 3 (Ball Speed: Low, Medium, High) with repeated measures on the last two factors. Post hoc comparisons were conducted with an LSD test to examine the main effects, while *t* tests were used to elucidate interaction effects. Significance level was set at $P < 0.05$ and effect size was provided by partial eta squared (η_p^2).

Results

ANOVA showed a main effect of Group [$F(2,20) = 6.931$, $P < 0.01$, $\eta^2 = 0.390$] and Time [$F(2,40) = 30.756$, $P < 0.001$, $\eta^2 = 0.606$], revealing that the Stereo+ group outperformed both other groups, and that performance increased with time. The main effect of Ball Speed [$F(2,40) = 76.388$, $P < 0.001$, $\eta^2 = 0.793$] indicated a systematic increase in performance with decreasing ball speed, all speeds being significantly different from each other (Table 1). More pertinent to the aim of this study, a significant Group × Time interaction indicated that the progress in the Stereo+ group was much more pronounced than in the other groups [$F(4,40) = 6.654$, $P < 0.001$, $\eta^2 = 0.400$]. Further analysis of this interaction showed that the Stereo+ group improved from pretest to posttest [$F(2,14) = 38.699$, $P < 0.001$; pre-post $P < 0.001$] and that this performance gain persisted after the retention period (post-retention: ns; pre-retention, $P < 0.001$). The increase in catching performance failed to reach significance in the Stereo− group [$F(2,10) = 4.151$, $P = 0.10$] and in the Control Group [$F(2,16) = 2.540$, $P = 0.11$]. The Group × Time × Speed interaction did not reach significance either [$F(8,80) = 1.703$, $P = 0.11$, $\eta^2 = 0.146$] (Fig. 1).

Discussion

This study is the first to show that poor catchers with a lack of stereopsis showed only a moderate and non-significant improvement in catching performance after an intensive, 2-week training period including more than 1,400 trials. Their counterparts with good stereopsis increased their success rate by about 400% when catching at the training speed, a performance gain that persisted after a 2-month retention period. The absence of a significant Group × Time × Speed interaction shows that the Stereo+ group outperforms the other groups at the post-test and after a retention period, irrespective of the ball speed tested.

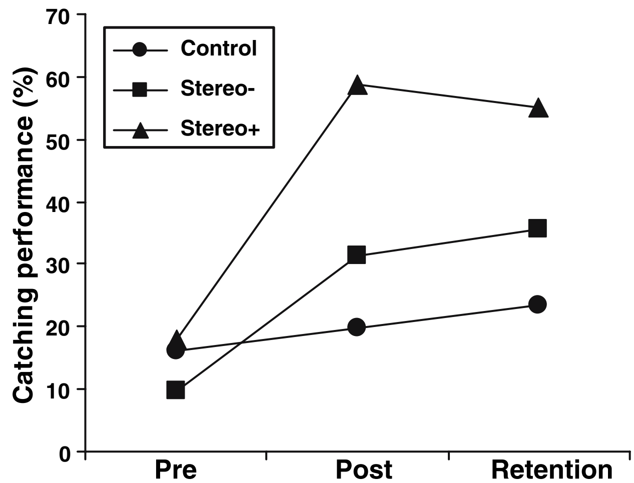

Fig. 1 The group by time interaction effect on catching performance

There is evidence that a detrimental stereo vision can be compensated for by visual strategies that imply the use of other depth cues (e.g. Marotta et al. 1995). Alternative depth cues might prove useful in situations where temporal constraints are not too severe, like in braking and parking a car in the conditions described in the study by Bauer et al. (2000). Our results show that such compensations may not be sufficient to successfully deal with interceptive tasks under high temporal constraints (Lenoir et al. 1999; Mazyn et al. 2004). Even more importantly, a lack of stereopsis cannot easily be compensated for by task-specific and extensive training either.

However, having a lack of stereo vision is not necessarily tantamount to being unable to learn to catch a ball. First, the considerable between-subject variability in catching performance (Table 1) in the Stereo− group at the posttest and retention test is mainly caused by one subject whose learning curve is very similar to the Stereo+ group. This participant eventually ended up with a catching performance of almost 70%. She might have learnt to use other (monocular) information sources to obtain depth perception or time-to-contact information far more efficiently than the other subjects with weak stereo vision, and integrate this information in the ongoing catching action. This is in line with the anecdotal evidence of elite performances in pilots having monocular vision only for example (Fielder and Moseley 1996; Regan 1997). In this respect, a considerable between-subject variability after the learning period was also observed in the Stereo+ group, which speaks for the use of other informational variables, or to a more of less successful combination of the information sources available. Second, data in Table 1 show that the Stereo− group did make some progress, although their performance increase failed to reach statistical significance. This tendency even remained when the participant mentioned above with a "normal" learning curve was omitted from the analysis.

Training at a single ball speed might open the window for the use of very specific information sources, for example the absolute looming rate of the approaching ball. However, the lack of a significant group × time × speed interaction suggests that transfer to other speed conditions has occurred, which is also evident from the pre-post comparison of catching performance at the highest and the lowest ball speed in both experimental groups.

In sum, this study shows that a weak stereo vision negatively affects interceptive performance under temporal constraints, and also jeopardizes potential learning effects in a specific training setting. However, some progress is possible, and in some cases this specific visual condition does hardly impair learning at all. The possibility remains that people with a lack of stereo vision might reach performance levels of unimpaired subjects when much more learning time is provided. These findings are of particular importance for patients active in sports (ball sports) or traffic situations (truck or taxi drivers), who should be aware of their limited depth perception in situations of increased temporal constraints.

References

Bauer A, Kolling G, Dietz K, Zrenner E, Scheifer U (2000) Are squinters second-class motorists? Influence of stereoscopic disparity on driving performance. Klinische Monatsblätter für Augenheilkunde 217:183–189

Collewijn H, Erkelens CJ (1990) Binocular eye movements and the perception of depth. In: Kowler E (eds) Eye movements and their role in visual and cognitive processes. Elsevier, Amsterdam, pp 213–261

Cutting JE, Vishton PM (1995) Perceiving layout and knowing distances: the integration, relative potency, and contextual use of different information about depth. In: Epstein W, Rogers S (eds) Perception of space and motion, 2nd edn. Academic, San Diego, pp 69–117

Fielder AR, Moseley MJ (1996) Does stereopsis matter in humans? Eye 10:233–238

Judge SJ, Bradford CM (1988) Adaptation to telestereoscopic viewing measured by one-handed ball-catching performance. Perception 17:783–802

Kuang TM, Hsu WM, Chou CK, Tsai SY, Chou P (2005) Impact of stereopsis on quality of life. Eye 19:540–545

Lenoir M, Musch E, La Grange N (1999) Ecological relevance of stereopsis in one-handed catching. Percept Mot Skills 89:495–508

Mazyn L, Lenoir M, Montagne G, Savelsbergh GJP (2004) The contribution of stereo vision to one-handed catching. Exp Brain Res 157:383–390

Marotta JJ, Perrot TS, Nicolle D, Servos P, Goodale MA (1995) Adapting to monocular vision: grasping with one eye. Exp Brain Res 104:107–114

Patterson R, Wayne LM (1992) Human stereopsis. Hum factors 34:669–692

Regan D (1997) Visual factors in hitting and catching. J Sports Sci 15:533–558

Rushton SK, Wann JP (1999) Weighted combination of size and disparity: a computational model for timing a ball catch. Nat Neurosci 2:186–190

Savelsberhg GJP, Whiting HTA (1992) The acquisition of catching under monocular and binocular conditions. J Mot Behav 24:320–328

van der Kamp J, Bennett SJ, Savelsbergh GJP, Davids K (1999) Timing a one-handed catch II. Adaptation to telestereoscopic viewing. Exp Brain Res 129:369–377