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The paddle move commonly used in magic tricks as a means for analysing the perceptual limits of combined motion trajectories

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Abstract. Following Gustav Kuhn's inspiring technique of using magicians' acts as a source of insight into cognitive sciences, we used the 'paddle move' for testing the psychophysics of combined movement trajectories. The paddle move is a standard technique in magic consisting of a combined rotating and tilting movement. Careful control of the mutual speed parameters of the two movements makes it possible to inhibit the perception of the rotation, letting the 'magic' effect emerge—a sudden change of the tilted object. By using 3-D animated computer graphics we analysed the interaction of different angular speeds and the object shape/size parameters in evoking this motion disappearance effect. An angular speed of 540° s^{-1} (1.5 rev. s^{-1}) sufficed to inhibit the perception of the rotary movement with the smallest object showing the strongest effect. 90.7% of the 172 participants were not able to perceive the rotary movement at an angular speed of 1125° s^{-1} (3.125 rev. s^{-1}). Further analysis by multiple linear regression revealed major influences on the effectiveness of the magic trick of object height and object area, demonstrating the applicability of analysing key factors of magic tricks to reveal limits of the perceptual system.

1 Introduction

Magic tricks can be fun—they can also be a rich source of insight into perceptual processing, particularly into specific cognitive bottlenecks. For instance, Barnhart (2010) recently identified two Gestalt principles exploited by magicians to deceive their audience: accidental alignment and the principle of good continuation. These findings extended the technique established by Gustav Kuhn and collaborators (eg Kuhn et al 2008; Kuhn and Land 2006; see also Macknik et al 2008; Martinez-Conde and Machnik 2007) for the systematic use of magic tricks for research. In accordance with this, we used the paddle move which is employed by conjurers in many tricks (magic knife trick, the hot rod, jumping peg paddle) to systematically analyse the perceptual limits of combined movement trajectories. Gardner (1978) suggested that the move has its name from its similarity to a move used by pitchmen in demonstrating paddle tricks. The origins of the paddle move are not known, but it is definitely a very old magic technique. In fact, a slightly different version of the move is already explained in Edwin Sachs's classic *Sleight of Hand*—a practical manual of legerdemain for amateurs and others from the 19th century (Sachs 1885/1980).

The paddle move is based on a combined tilting and rotary movement of a rather small oblong object, held between thumb and first finger (see figure 1).

If the trick works, the rotary movement will not be seen by the observer. Conjurers often use the object move with props like paddles, pens, knives, or matchboxes. The move can be used effectively to make things vanish (eg performer first shows a beautiful little gem on both sides of a rod, then with a magic gesture the gem disappears on both sides), to materialise objects (eg the gem appears on a previously empty rod) or to change their colour (eg a red knife turns white or vice versa). See figure 2 for an illustration of the sequential movements of a paddle typically used for such 'magic' demonstrations.

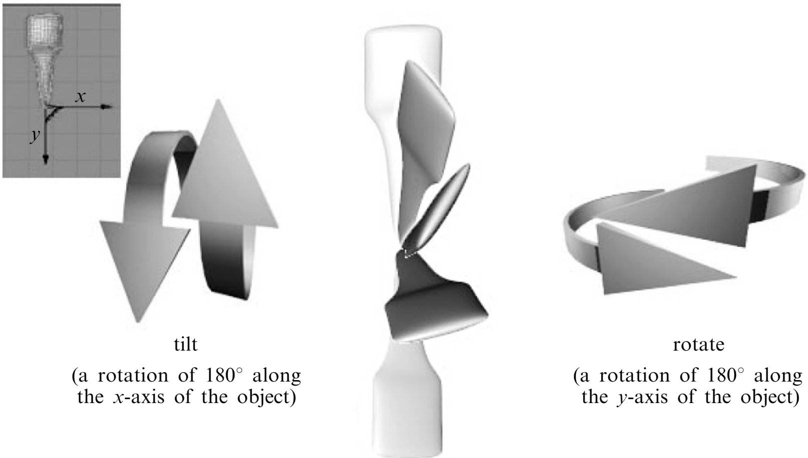

Figure 1. The scheme of the 'paddle move'—a tilting and rotary movement. The aim of the legerdemain is to move the object so that the rotation is not seen.

The trick belongs to the standard repertoire of top performers (for instance, the former FISM winner Juan Tamariz from Spain; FISM stands for Fédération Internationale de Sociétés Magiques). For a magician, it is important to perform the move gently and naturally so that the spectator does not suspect any trickery. As pointed out by Kuhn et al's (2008) taxonomy of magic tricks, the spectator's knowledge of the technique could cause specific attention to reveal the secret behind the effect, which might easily ruin the trick. Thus, the magicians' experiences tell us that the move should be performed at a speed and in a manner which is natural for showing the backside of an object. The critical rotary movement should be performed in the middle of the tilting movement (personal communication from an experienced performer of the magic knife trick and former member of the Magic Circle in Vienna, Dr Christian Fidi, who is also a former prize winner at the International Magic Convention in London). "Hence the move need not be made rapidly. It should be fast enough to hide the double turn, but slow enough to appear off-hand and natural" (Gardner 1978, page 280). Here, we aimed to investigate from a scientific point of view the factors necessary for the perfect illusion—the effectiveness of the trick thus could be used as the target criterion. This, in turn, provides important information on the cognitive limitations of processing two concurrent, non-uniform motion trajectories.

Motion perception and detection of minimal movement in the field of vision are of evolutionary relevance, for instance, for detecting potential prey or danger. Systematic research on the variables influencing motion perception extends back to Wertheimer (1912) and Brown (1927) in the early 20th century, who concluded that perceived speed differs from physical motion depending on the context. Object size as well as the extent of the surrounding area affects visual perception. Following Brown's work, Sokolov et al (1997) determined the relationship between physical speed and perceived speed. Their findings indicate that the larger an object and/or its reference system is, the faster its physical speed should be for a given perceived speed. A great number of studies have been carried out on visual motion perception phenomena and factors that influence them (Flach et al 2004; Gregory and Heard 1983; Haarmeier and Thier 1998; Harvey and Braddick 2008). Object characteristics, such as form and contours, have been considered in the first place. Ludvigh and Miller (1958) described a significant deterioration of visual acuity during ocular pursuit of moving objects when the speed was increased. Visual acuity was therefore divided into static and dynamic. Miller (1958) established that retinotopic movement was due to the decline of dynamic visual acuity rather than extrafoveal mapping. According to his finding, essential aspects of visual motion perception are object form, object size, and speed. Owing to the limited capacity of human vision, the system has to balance the reduced visual perception by interpolating missing information (Yantis 1995). For instance, the experience of the film industry shows that static images presented with a frequency of approximately 16 similar frames per second are interpreted as belonging together and evoking the perception of moving pictures. The distribution of one's attention and conspicuousness of the stimuli determine the concept of awareness of time. The more conspicuous element attracts higher attention and becomes the major presence (Kuhn and Land 2006). This leads to selective perception by combining form and motion information (von Muhlenen and Muller 2000; Tse and Logothetis 2002). An illusion may be the result of this temporal sampling by the visual system. Many different misperceptions have been reported. Finlay et al (1984) described the illusion of reversed motion known as the wagon-wheel effect. Kline and Eagleman (2008) found evidence against temporal sampling account of an illusory motion reversal. Other illusions, such as the illusory bending of a rigidly moving line segment have been reported (Thaler et al 2007). A common feature of them is that they may all be due to the observer's inability to track rapid image displacement.

Motion perception is an important everyday task and has been extensively studied psychophysically, electrophysically, and computationally. For instance, thresholds of perceiving moving targets with a visual angle of about 1 min ($\frac{1}{60}^{\circ}$) for real motion and only about 0.5 min ($\frac{1}{120}^{\circ}$) for apparent motion at durations of up to 500 ms (see Sokolov and Pavlova 2006) demonstrate high sensitivity of the perceptual system to movement. Although research on single motion trajectories is extensive, that on combined motion trajectories is still sparse. There are some studies on so-called 'multiple motions', but we include in this category only motion patterns of multiple objects having different, but unique, motion trajectories. The complex combination of different motion trajectories, such as tilting and rotating, in a single object has not yet been the subject of systematic research (Derrington et al 2004; Grzywacz and Merwine 2003).

2 Experiment

The present experiment was designed to examine these theories in a different context. Is there a combination of movements leading to an unseen motion effect? The paddle move is appropriate to investigate the findings explained here and follows the idea of Kuhn et al (2008) and Macknik et al (2008) of using magic tricks for investigating fundamental processes in vision science. As the success of the paddle move is strongly dependent on the magician's proficiency and is thus susceptible to personal biases, we decided to transfer the trick to the domain of virtual reality. By constructing a 3-D model of a typical sequence of combined movements we are able to independently vary object size/shape and the angular velocities of the two movements. When using psychophysics of concurrent motions, it is very useful to have a single target criterion revealing the threshold of the detection task. We can use the effectiveness of the magic trick (whether it 'works' or 'not', to establish whether it is not being noticed or indeed being noticed) as the target criterion. With systematically varied parameters of central importance for detecting motion we will show which specific parameters, and most importantly, which combinations of these parameters are needed to perform the paddle move successfully.

2.1 *Method*

2.1.1 *Stimuli and independent variables.* To maintain full control, the paddle move was made by computer animation, with the program Blender 2.48.[1] Figure 1 shows the scheme of the paddle move, figure 2 illustrates one full cycle of the trick in eight steps.

[1] Blender is an open-source 3-D graphics application. For further information visit the website blender.org.

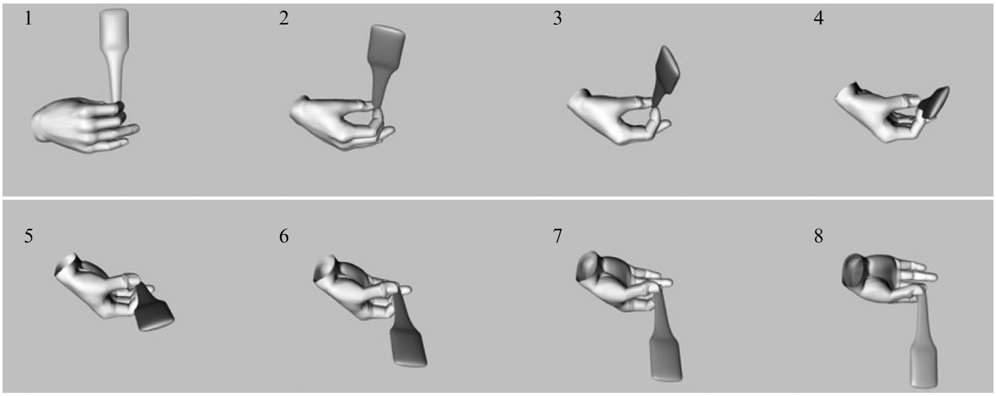

Figure 2. The paddle move illustrated by a tilting and rotating paddle in eight consecutive steps.

The aim of the trick is to make the observer believe that the paddle was only tilting but not rotating. To find when the rotary motion is not perceived, we varied the speed of tilting, the size/form of the object used, and the tilt angle. The speed was defined by the progress of rendering the scene. To achieve a fluent motion the scene was rendered at 25 frames s^{-1}. Speed increased when frames showing the 180° of tilt were reduced (table 1).

Table 1. Observed velocities of the tilting and rotary movement. Tilting speed increased when frames were reduced. The rotary speed depends on the tilting speed.

Tilting speed ° s^{-1} (rev. s^{-1})		Frames to animate movement	Rotary speed/° s^{-1} (rev. s^{-1}) over tilting distance: whole 180°		two thirds (0° – 120°; 60° – 180°)		one third (0° – 60°; 60° – 120°; 120° – 180°)	
180	(0.50)	25	180	(0.50)	270	(0.75)	540	(1.50)
375	(1.04)	12	375	(1.04)	562.5	(1.56)	1125	(3.13)
500	(1.39)	9	500	(1.39)	750	(2.08)	1500	(4.17)
750	(2.08)	6	750	(2.08)	1125	(3.13)	2250	(6.25)

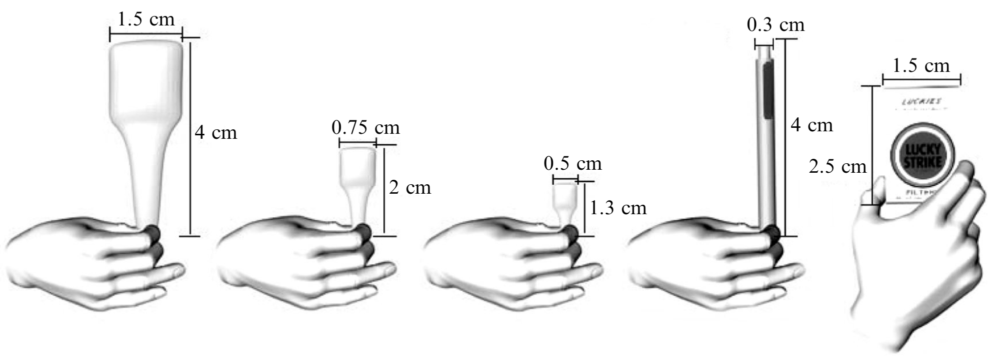

Figure 3. Objects used to demonstrate the movement. The aspect ratios of the objects used are shown.

Three different objects, a paddle (in three sizes), a pen, and a cigarette packet were presented (figure 3). We were mainly interested in studying the paddle move with the prop that magicians most often use for the effect, namely the paddle. The pen and the cigarette packet were also chosen to compare the results from the paddle (which is a natural prop for conjurers, but rather unfamiliar to lay people) with that produced by more common objects: the pen was chosen because it is an example of a common elongated object, whereas the cigarette packet has a greater width.

The length of the paddle was 2.6 times its width. The height-to-width ratio of the pen was 13.3 and that of the cigarette packet was 1.6. These five objects were each presented at four tilting velocities with six different rotary movements (see table 1). Hence, there were 120 different trial types. In each case a static picture of the object was shown for 1 s (25 frames). Then the object tilted over by 180° at the specified speed. After a pause of 1 s the object tilted at the same speed back to its starting position.

2.1.2 *Apparatus.* All stimuli were viewed in a normally illuminated room on a 15.4-inch CrystalView wide-screen display (FSC Amilo A1650G; ATI Radeon Xpress 200M; 1280×800 pixels). The active display area was 480 pixels wide $\times$ 360 pixels high (12.5 cm $\times$ 9.5 cm) and was positioned at an average reading distance of approximately 50 cm from the observer, yielding a visual angle of about 7.1 deg $\times$ 5.4 deg. To produce typical inspection conditions no chin-rest was used and the viewing was binocular. Stimuli were presented in shockwave-flash player files (.swf). [A movie file can be found on the Perception website at http://dx.doi.org/10.1068/p6866.]

A preliminary-test on 43 subjects showed that the experimental setting was adequate in evoking the typical outcome of the paddle move with participants not detecting the second movement in several conditions.

2.1.3 *Procedure.* The experimenter first verified the observers' eyesight with an eye-chart test. Observers with normal or corrected-to-normal vision were allowed to participate. The experimental setting was implemented in a web-based questionnaire. To start with, the observers were introduced to the experiment by explaining three different movements demonstrated in short gif-animated (graphics interchange format) pictures. Observers were then prompted to answer the question whether the object was solely rotated, solely tilted, or rotated and tilted by clicking the appropriate response button. After a sample item, the test started. Items were generated randomly from the pool of 120 items described here earlier, and each item was presented once. Five start items introduced the different objects and were excluded from subsequent analysis. Items were changed automatically by clicking one of the three answer buttons. Observers were able to pause whenever they chose. Since every item consisted of the combination of a rotary and tilting movement, the dependent variable was the perception of the rotary movement. Independent variables were speed, object form, and object size.

2.1.4 *Participants.* 172 observers (88 female; aged between 19 and 62 years; mean age = 29.6 years, SD = 9.2 years) participated in the experiment. They were naive to the purpose of the study. All procedures were performed in accordance with the ethical standards laid down by the World Medical Association in the 2008 Declaration of Helsinki.

2.2 *Results*

Participants' responses were first classified in terms of having or not having perceived the rotary movement, used as the measure of effectiveness of the trick. Figure 4 shows a clear monotonic function with higher percentages for higher tilting speeds for all objects together; figure 5 illustrates this for the paddle object only, split by paddle sizes; figure 6 shows these data for objects of same height: the large paddle and the pen.

It is also clear that the rotary movement was an important factor for effectiveness of the trick, with maximum effectiveness at 60°–120°, followed by 0°–60° and 120°–180° (figure 4). A highly significant main effect of object size was revealed by a χ^2-test for the smallest paddle (1.3 cm) rotated between 60° and 180° [$\chi^2_{1,172} = 110.7$, $p < 0.0001$] and 60° and 120° [$\chi^2_{1,172} = 114.0$, $p < 0.0001$]. This confirms the prediction that size matters.

In accordance with the assumption that object form affects the perception of the rotary movement, the illusion occurred also at a slower speed (500° s^{-1}) but only when presented with the 'pen' at a tilt angle of 60°–120°, $\chi^2_{1,172} = 12.3$, $p < 0.0001$.

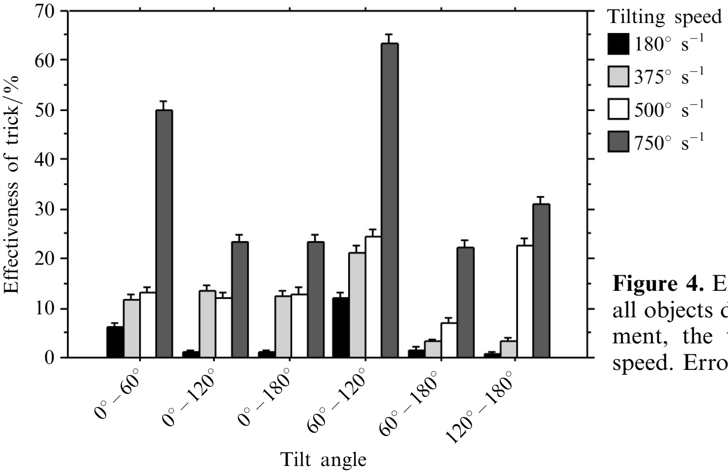

Figure 4. Effectiveness of the trick for all objects depending on rotary movement, the tilt angle, and the tilting speed. Error bars indicate 1 SEM.

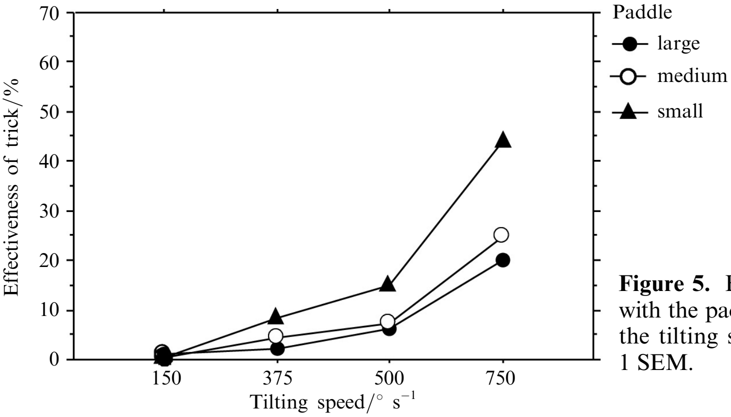

Figure 5. Effectiveness of the trick with the paddles only, as a function of the tilting speed. Error bars indicate 1 SEM.

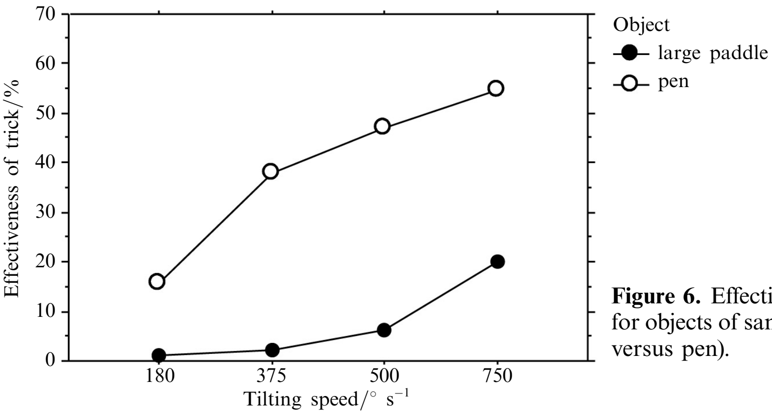

Figure 6. Effectiveness of tilting speed for objects of same height (large paddle versus pen).

After aggregating the tilt angle, we further analysed the impact of object size solely for the three paddles by employing a within-subjects analysis of variance (ANOVA) with the two factors: tilting speed (180° s^{-1}, 375° s^{-1}, 500° s^{-1}, and 750° s^{-1}) and object size (small, medium, large). We obtained main effects of tilting speed ($F_{3,513} = 743.6$, $p < 0.0001$, $\eta_p^2 = 0.813$), and object size ($F_{2,342} = 171.7$, $p < 0.0001$, $\eta_p^2 = 0.501$), as well as an interactive effect between the two factors ($F_{6,1026} = 57.5$, $p < 0.0001$, $\eta_p^2 = 0.252$). For all object sizes, significant simple main effects of speed were obtained, with $\eta_p^2 = 0.664$ for the large, $\eta_p^2 = 0.760$ for the medium, and $\eta_p^2 = 0.898$ for the small paddle.

Further tests for simple main effects showed that increasing effects of object size were obtained from a minimum tilting speed of 375° s^{-1} with $\eta_p^2 = 0.177$ for 375° s^{-1}, $\eta_p^2 = 0.273$ for 500° s^{-1} and $\eta_p^2 = 0.622$ for 750° s^{-1}.

We further tested the predictors for the effectiveness of the trick with multiple linear regression with the predictors tilting speed and size factors of the objects used: width, height, and area (simplified as width × height). As input we used the 120 different experimental conditions. By conducting a stepwise regression we identified speed: $\beta = 0.517$, $p < 0.0001$, height: $\beta = 0.419$, $p < 0.0001$, and area: $\beta = -0.551$, $p < 0.0001$ as significant predictors with a total explained variance of 51.8% ($R = 0.720$, $F_{3,119} = 41.6$, $p < 0.0001$, $\eta_p^2 = 0.518$).

Thus, the trick was the more effective the greater the speed, the longer the object, and the smaller the area of the object. This means that when the object was very elongated, the magic trick was highly effective. This could be attributed to two factors. First, in the experimental design we used, height proportionally increases the tangential speed. Second, as we used the usual objects of a magic trick—paddles, a pen, and a cigarette box—height was also related to specific form factors; thus height and width were not experimentally crossed. However, we used two objects with the same height—the large paddle and the pen—so we were able to analyse the variable width for these two objects (figure 6). To differentiate between the two potential explanations for the effectiveness of the trick, we employed an additional within-subjects ANOVA for these two objects only. The ANOVA consisted of two factors, tilting speed (180° s^{-1}, 375° s^{-1}, 500° s^{-1}, and 750° s^{-1}), and object width (pen: 0.3 cm, large paddle: 1.5 cm). We obtained large main effects of tilting speed ($F_{3,169} = 293.3$, $p < 0.0001$, $\eta_p^2 = 0.839$) and object width ($F_{1,171} = 1177.4$, $p < 0.0001$, $\eta_p^2 = 0.873$), as well as an interactive effect between these variables ($F_{3,169} = 96.6$, $p < 0.0001$, $\eta_p^2 = 0.632$) (see figure 6). For both objects, significant simple main effects of speed were obtained, with $\eta_p^2 = 0.782$ for the pen and $\eta_p^2 = 0.664$ for the large paddle. With further simple main analyses of object width we could also show that the magic trick was more effective for the object with smaller width for all levels of speed, with effect sizes of $\eta_p^2 > 0.574$.

3 General discussion

The primary aim of our experiment was to employ Kuhn et al's (2008) suggestion to use magicians' intuitive knowledge on perceptual processes to reveal essential variables for the accurate perception of complex patterns of motion trajectories. We used a well-known magic trick in which typically a paddle is simultaneously rotated and tilted leading to a disappearance effect of the rotary movement. By using computer-simulated sequences we were able to carefully control three key variables: speed, object size/form, and tilt angle. The test criterion was defined as the effectiveness of the magic trick: whether the participant perceives or does not perceive the secondary rotary movement.

We identified the most important variables for such a motion disappearance effect. There was a dominant speed effect in this setup. Independent of the form and size of the object, the illusion occurred solely at the fastest speed (750° s^{-1})—this might be the lower limit of producing a stable effect using the paddle move. As stated, magicians' experiences teach us that the effect can be achieved at a speed slow enough to appear natural but fast enough to hide the rotary motion. Our findings show that the natural speed of turning over such an item is rather high. In line with Barnhart's (2010) considerations, it seems that the visual system confronted with two motion trajectories where the speed of one of these motions comes close to its perceptual limits decides in favour of the most simple selection: only one dominant motion trajectory can be perceived; thus, evidently, there is only one motion trajectory. Apart from the general effect of speed, the form factor of the object used was also of relevance.

Multiple regression analysis shows that object height as well as object area (defined as width × height of the object) both affect the effectiveness of the trick. The magic trick was most effective whenever the object was very elongated. This could be attributed to two factors: (i) higher tangential speed at the apex of the object, (ii) narrower shape of these objects. Both factors were found to be relevant by an additional ANOVA. These findings also confirm magicians' preferred use of elongated objects such as rods or knives for performance of the paddle move.

In sum, our findings demonstrate that, although the present magic trick can be optimised with the use of more elongated and thin objects, especially the pen, the misperception also occurs with all other objects when the speed is set high enough. This also confirms that the general setting of a complex pattern of motion trajectories is indeed conducive to a 'magic trick'. Our results also indicate that the best time of rotation (rotary movement) is while tilting the object from 60° to 120°. This finding also confirms the experiences of magicians that the rotary motion should not start at the same time as the layer tilting motion and should finish well before it. To sum up, by simulating such complex procedures as in the present experiment we can not only deepen the understanding of such 'magic tricks', but also use the analysed parameters for obtaining more insight into the cognitive processing and its limitations regarding such complex motion patterns.

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References

Barnhart A S, 2010 "The exploitation of Gestalt principles by magicians" *Perception* **39** 1286 – 1289

Brown J F, 1927 "Über gesehene Geschwindigkeiten" *Psychologische Forschung* **10** 84 – 101

Derrington A M, Allen H A, Delicato L S, 2004 "Visual mechanisms of motion analysis and motion perception" *Annual Review of Psychology* **55** 181 – 205

Finlay D, Dodwell P, Caelli T, 1984 "The wagon-wheel effect" *Perception* **13** 237 – 248

Flach R, Knoblich G, Prinz W, 2004 "The two-thirds power law in motion perception" *Visual Cognition* **11** 461 – 481

Gardner M J, 1978 *Encyclopedia of Impromptu Magic* (Chicago, IL: Magic)

Gregory R L, Heard P F, 1983 "Visual dissociations of movement, position, and stereo depth: Some phenomenal phenomena" *Quarterly Journal of Experimental Psychology A* **35** 217 – 237

Grzywacz N M, Merwine D K, 2003 "Neural basis of motion perception" *Encyclopedia of Cognitive Science* **3** 86 – 98

Haarmeier T, Thier P, 1998 "An electrophysiological correlate of visual motion awareness in man" *Journal of Cognitive Neuroscience* **10** 464 – 471

Harvey B M, Braddick O J, 2008 "Psychophysical differences in processing of global motion and form detection and position discrimination" *Journal of Vision* **8**(7):14, 1 – 18

Kline K A, Eagleman D M, 2008 "Evidence against the temporal subsampling account of illusory motion reversal" *Journal of Vision* **8**(4) 13.1 – 13.5

Kuhn G, Amlani A A, Rensink R A, 2008 "Towards a science of magic" *Trends in Cognitive Sciences* **12** 349 – 354

Kuhn G, Land M F, 2006 "There's more to magic than meets the eye" *Current Biology* **16** R950 – R951

Ludvigh E, Miller J W, 1958 "Study of visual acuity during the ocular pursuit of moving test objects. I. Introduction" *Journal of the Optical Society of America* **48** 799 – 802

Macknik S L, King M, Randi J, Robbins A, Teller, Thompson J, Martinez-Conde S, 2008 "Attention and awareness in stage magic: turning tricks into research" *Nature Reviews Neuroscience* **9** 871 – 879

Martinez-Conde S, Macknik S L, 2007 "Science in culture: Mind tricks" *Nature* **448** 414

Miller J W, 1958 "Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination" *Journal of the Optical Society of America* **48** 803 – 808

Muhlenen A von, Muller H J, 2000 "Perceptual integration of motion and form information: Evidence of parallel-continuous processing" *Perception & Psychophysics* **62** 517 – 531

Sachs E T, 1885/1980 *Sleight of Hand. A Practical Manual of Legerdemain for Amateurs and Others* (New York: Dover)

Sokolov A N, Ehrenstein W H, Pavlova M A, Cavonius C R, 1997 "Motion extrapolation and velocity transposition" *Perception* **26** 875 – 889
Sokolov A, Pavlova M, 2006 "Visual motion detection in hierarchical spatial frames of reference" *Experimental Brain Research* **174** 477 – 486
Thaler L, Todd J T, Spering M, Gegenfurtner K R, 2007 "Illusory bending of a rigidly moving line segment: Effects of image motion and smooth pursuit eye movements" *Journal of Vision* **7**(6):9, 1 – 13
Tse P U, Logothetis N K, 2002 "The duration of 3-D form analysis in transformational apparent motion" *Perception & Psychophysics* **64** 244 – 265
Wertheimer M, 1912 "Experimentelle Studien über das Sehen von Bewegung" *Zeitschrift für Psychologie und Physiologie der Sinnesorgane* **61** 161 – 265
Yantis S, 1995 "Perceived continuity of occluded visual objects" *Psychological Science* **6** 182 – 186

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