2008

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Publication Details

Prowse, G., Palmisano, S. A. & Favelle, S. K. (2008). Time-To-Contact Perception During Simulated Night Landing. International Journal of Aviation Psychology, 18 (2), 207-223.

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Abstract

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Keywords

Time, Contact, Perception, During, Night, Landing

Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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TIME-TO-CONTACT PERCEPTION DURING SIMULATED NIGHT LANDING

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Running head: TTC perception during night landing

Keywords: Visual landing, Time-to-contact, Optic flow, Glideslope

Abstract

In two experiments, non-pilots made time-to-contact (TTC) judgments during simulated oblique descents towards a ground–plane. Experiment 1 revealed a significant effect of simulated glideslope on TTC judgments: 3 degree simulations were underestimated, 6 degree simulations were generally accurate, and 9 degree simulations were overestimated. However, there was a significant reduction in this glideslope effect when the simulated aimpoint was explicitly (as opposed to implicitly) identified throughout the display. This glideslope effect was also found to disappear in Experiment 2, when aimpoint distance was held constant for all glideslopes - suggesting that TTC was being indirectly calculated based on perceived distance.

During the final stages of an aircraft landing, the pilot must reduce the plane's sink-rate (descent velocity) in order to obtain a safe, smooth landing (Grosz et al, 1995; Mulder et al, 2000). Just prior to touchdown, the pilot will pull back on the control column to increase the aircraft's (nose-up) angle of attack. This landing flare maneuver produces an increase in the plane's lift force which, if performed correctly, should reduce its sink-rate to acceptable levels. The landing flare is considered one of the most technically demanding aspects of piloting and its improper timing and execution has been implicated in a significant proportion of landing incidents (Benbassat & Abramson, 2002). In a recent questionnaire study, Benbassat and Abramson (2002) reported that 87 percent of pilots sampled utilised vision in timing the initiation of the flare, though alarmingly, no consensus emerged as to which specific cues were required for a successful landing.

In principle, pilots could use visual information about their perceived time-to-contact (TTC) with the runway to time the initiation of their landing flare (Flach & Warren, 1995). Observer motion through the world generates a pattern of visual motion referred to as optic flow (Gibson, 1950). Gibson, Olum and Rosenblatt (1955) demonstrated that the focus of expansion (FOE) of this optic flow provides information about the location of the aircraft's impending contact with the tarmac. The time remaining until contact with the FOE or *aimpoint* is referred to as TTC. The method by which TTC is accessed from optic flow is still a matter of much debate (Regan & Gray, 2000). Indirect perceptual theories suggest that TTC is calculated in staged processes, where the perceived distance to impact is essentially divided by the observer's perceived approach velocity (Gray & Regan, 2000). However, TTC may also be obtained directly from the optical flow presented to the pilot (e.g. Tresilian, 1991).

Lee (1976) suggested that TTC could be directly determined via the rate of change in the optical size of an object during self- or object motion in depth. For example, during a constant velocity self-motion, the rate of an object's retinal image expansion will be inversely related to the time remaining for the observer to reach the object (Bootsma & Craig, 2003). Designated *Tau* (τ), this monocularly available information about TTC is specified as follows:

$$TTC \approx \tau = \theta/(d\theta/dt),$$

There are three different versions of this tau equation (Kaiser & Mowafy, 1993). In the case of Local tau type I ($\tau_L^{(1)}$), θ is defined as the instantaneous, optical angular distance between any two designated points contained within a rigid object's surface (Tresilian, 1991). In the case of Local tau type II ($\tau_L^{(2)}$), θ is defined as the angular distance between the optical boundaries of an object (Lee, 1976; Tresilian, 1991). Finally, in the case of Global tau (τ_G), θ is defined as the angular distance between an element point within the optic flow field and the observer's aimpoint (Tresilian, 1991, 1993). In all three cases, $d\theta/dt$ is the instantaneous rate of angular expansion of these angular distances over time. However, these particular formulae are only valid when the observer (or the object) is moving at a constant velocity and the object or surface feature lies perpendicular to the direction of this motion (Warren, 1995). Note that accurate perception of TTC based on τ_G presupposes accurate perception of the location of the aimpoint.

TTC Perception During an Oblique Approach towards a Runway

During an oblique approach toward a planar surface, the optic flow projected on to the retina above and below the aimpoint varies asymmetrically in both velocity and direction (Gibson et al., 1955; Warren, 1995). Mulder et al. (2000) denote the *aiming line* as the hypothetical dividing line between these two optical areas. Optical information above the aiming line (i.e. between the aiming line and the horizon) will lead to an overestimation of TTC due to a slower rate of expansion (relative to the aiming line). Conversely, optical information below the aiming line will lead to underestimation of TTC due to a faster rate of expansion. Thus, $\tau_L^{(2)}$ does not accurately reflect TTC during an oblique approach – as it is based on the optical expansion of an entire object. $\tau_L^{(1)}$ and τ_G will, however, accurately indicate TTC, but only when they are based on the optical expansion of elements lying on the aiming line (Mulder et al, 2000). These modified versions of τ, which will be referred to henceforth as *restricted local tau type I* ($R\tau_L^{(1)}$) and *restricted global tau* ($R\tau_G$), are defined as follows:

$$TTC \approx R\tau_L^{(1)} = \theta_{ALw}/(d\theta_{ALw}/dt),$$

$$TTC \approx R\tau_G = \theta_{ALtx}/(d\theta_{ALtx}/dt),$$

Where θ_{ALw} is the instantaneous visual angle formed between any two points lying along the aiming line, and $d\theta_{ALw}/dt$ is the angular rate of expansion of these two points over time. Similarly, θ_{ALtx} is the instantaneous visual angle formed between a texture element located at some point along the aiming line and the aimpoint, and $d\theta_{ALtx}/dt$ is the rate of expansion this angle projects over time (derived from Mulder et al., 2000).

Previous TTC Research into the Oblique Runway Approach

Grosz et al. (1995) suggested that pilots might utilize tau-based information about TTC to determine the moment of flare onset. In their study, three pilots participated in an active landing task during a simulated night approach. They found that pilots did not initiate their flares at a constant time-to-contact and performed more forceful flares when approaches had a higher sink rate. A later study by Mulder et al. (2000) investigated the effects of ground texture on flare timing by testing non-pilots in a simulated landing situation. They hypothesized that adding extra texture elements to a ground plane containing a runway outline would provide more optimal $R\tau_G$ information along the aiming line, thereby improving performance (as the expansion of each additional texture element relative to the aimpoint provides extra information about $R\tau_G$). Consistent with this notion, they found that displays that contained additional texture produced the most successful flare timing judgments. The highest simulated sink-rate produced the least successful judgments, indicating that flare timing difficulties increased with increasing sink-rate. The TTC at which the flare was initiated was also found to decrease as angular velocity increased. The addition of extra texture to the display weakened, but did not eradicate, this effect for all subjects.

Aimpoint Misperception and TTC Estimation

The findings of the Grosz et al. (1995) and the Mulder et al. (2000) studies suggested that flare timing judgments were inversely related to simulated sink-rate. However, if $R\tau_G$ governs flare timing, then performance should have been unaffected by the glideslope and sink rate differences in these studies (as optical expansion along the aiming line is affected by approach velocity, but not by the sink-rate). This suggests that either the $R\tau_G$ was not utilized or that perhaps $R\tau_G$ or $R\tau_L$(1) was incorrectly sampled at some location on the runway above or below the aiming line. For this to occur, the location of the FOE would have to have been misperceived. Tresilian (1993,

1995) has noted that any misperception of the FOE will bias TTC judgments based on global tau. Consistent with this notion, Palmisano and Gillam (2005) found evidence of heading estimation biases during simulated night landings, which varied significantly with the glideslope. Specifically, they found a downward bias for glideslopes below 3.1 degrees and an upward bias for glideslopes over 6.5 degrees. While this heading misperception account of flare timing errors would seem to provide a reasonable explanation of the Grosz et al. (1995) findings, it has more difficulty explaining the Mulder et al. (2000) findings (as an explicit aimpoint was provided in the latter study). The current experiments were therefore conducted in order to reexamine the effect of ground texture and simulated glideslope on TTC perception and the utility of $R\tau_G$ and $R\tau_L^{(1)}$ when the heading information is either explicitly or implicitly available.

EXPERIMENT 1

This experiment examined the perception of TTC during a night landing situation. The goal was to determine whether such percepts could be responsible for the accurate initiation (and subsequent control) of the landing flare. Thus, our experiments measured TTC estimates at various stages of the approach, rather than the onset of a simulated flare (as in previous studies)[1]. The displays used in Experiment 1 simulated a constant velocity oblique approach towards a ground plane consisting either of randomly positioned dots, a runway outline or a superimposed runway outline over random dot texture. Displays provided either an implicit aimpoint (specified by the optical flow) or an explicitly demarked aimpoint. If Grosz et al's (1995) and Mulder et al's (2000) previous failures to provide clear support for restricted tau accounts of flare timing were due to their participants' misperceiving their heading (as per Palmisano and Gillam, 2005), then we should expect TTC estimates for implicit aimpoint conditions to vary with differences in the simulated glideslope. The inclusion of an explicit aimpoint was designed to reduce the occurrence of heading misperceptions and facilitate access to $R\tau_G$ and $R\tau_L^{(1)}$ along the aiming line (as per Mulder et al, 2000). If $R\tau_G$ and $R\tau_L^{(1)}$ are utilized, then the TTC estimates should be accurate for each of the different simulated glideslopes when explicit heading information is provided. As Mulder et al. (2000) found an increase in successful flare timing judgments with the inclusion of added ground texture, and Palmisano and Gillam (2005) found improved heading accuracy for combined runway outline and dot element displays as compared to individual textures, it is expected in the current study that the absolute TTC estimates should demonstrate similar texture-based improvements.

Method

Participants. Participants were 22 undergraduate students from the University of Wollongong (20 female, 2 male) volunteering in exchange for course credit. Ages ranged from 18 to 50 years (*M* = 22.5 years). All reported normal or corrected-to-normal vision. As in the previous study by Mulder et al (2000), all of our participants were non-pilots – since professional pilots can be highly biased towards initiating the flare at a certain height (Grosz et al, 1995). The study protocol was approved in advance by the Wollongong University Ethics Review board. All participants provided the experimenter with written informed consent before commencing the experiment.

Apparatus. Displays were generated via a Macintosh G4 personal computer and presented through a Sony Trinitron Multiscan G420 monitor with a resolution of 1280 pixels (horizontal) by 1024 pixels (vertical) and an 85 Hertz refresh rate. Viewing distance was maintained at 40 cm via a chin rest, which aligned optical horizon with the participant’s eye level. The visual display area subtended a binocular viewing angle of 48.8 degrees (horizontal) and 37.3 degrees (vertical). The texture in these displays subtended visual angles of 48.8 degrees (horizontal) and 17.4 degrees (vertical).

Visual displays. Displays were similar to those utilized by Palmisano and Gillam (2005). Simulated self-motion was presented as an oblique descent towards a ground plane from an initial starting height of 29.85 m. Texture conditions included either 800 randomly distributed blue dots (dot-only) (containing $R\tau_G$ cues only) (luminescence *M* = 118 cd/m^2), a green runway outline (runway-only) (containing $R\tau_G$ and $R\tau_L^{(1)}$ cues) (simulated dimensions = 60 m wide by 1347 m long, luminescence *M* = 118 cd/m^2), or both 800 blue dots and green runway outline combined (runway-dot) (containing $R\tau_G$ and $R\tau_L^{(1)}$ cues) (see Figure 1). All display backgrounds were black (luminescence *M* = 0.2 cd/m^2). Dots were distributed one per cell over a non-visible grid superimposing the ground plane. The ground plane was truncated at 2 km for dot-only and runway-dot displays preventing pixel cluster towards the horizon. Hence, an implicit horizon was formed at approximately 0.7 degrees below the true horizon.

<INSERT FIGURE 1 ABOUT HERE>

Displays were presented either with or without a small, dimensionally static, green horizontal bar (explicit aimpoint). This explicitly or implicitly specified aimpoint coincided with the intersection of the glideslope vector and ground plane (corresponding to the FOE of the optic flow). Each display represented one of three different simulated glideslopes – approach angles of 3, 6 or 9 degrees towards the ground plane. As a result, the explicit/implicit aimpoint for the different glideslope conditions was located at different physical distances along the ground plane. The simulated TTC for each landing simulation was 4.02 sec, 6.52 sec, or 14.01 sec. The simulated sink rate was held constant for each of these simulated TTC conditions (i.e. the angular approach velocity was varied to compensate for the different aimpoint distances for each of the different simulated glideslopes).

Procedure. Prior to the experiment, participants passively observed three automated, exposure blocks, each of which consisted of the following displays: (1) runway-dot with explicit aimpoint, (2) runway-only with explicit aimpoint, and (3) dot-only with explicit aimpoint. This familiarized them with the experimental procedure and display characteristics without a task component. A Predicted Motion (PM) task was employed to obtain the TTC data (e.g. Delucia & Meyer, 1999; Hancock & Manser, 1997; Hecht, Kaiser, Savelsbergh, & van der Kamp, 2002; Manser & Hancock, 1996; Schiff & Oldak, 1990). During the experimental phase, simulated landing displays disappeared after 1 sec. The participant’s task was to wait for the appropriate time and then press the mouse button when they perceived that they would have made contact with the ground plane. Trial blocks were organized by aimpoint and texture display condition: (1) dot-only, (2) dot-only + explicit aimpoint, (3) runway-only, (4) runway-only + explicit aimpoint, (5) runway-dot, and (6) runway-dot + explicit aimpoint. The order of these blocks was randomly allocated for each participant. In each block participants were exposed to 4 repetitions of each simulated TTC condition (4.02, 6.52 and 14.01 sec) by glideslope condition (3, 6 and 9 degrees) combination, totaling 36 trials per block. Each trial block was administered twice, producing 432 trials overall.

Results

Data obtained from three participants was eliminated due to inconsistent responding. TTC error values were obtained by subtracting the simulated TTC value from the participant's estimated TTC value. A 3 (Texture) x 2 (Aimpoint) x 3 (Glideslope) x 3 (Simulated TTC), repeated measures analysis of variance (ANOVA) was performed on this TTC error data (α = .05). Whenever the assumption of sphericity was violated, the reported statistics are Greenhouse-Geisser corrected. The main effect of Texture type was significant $F(1.556, 28.004) = 9.169$, $p < .002$. Bonferroni adjusted post-hoc contrasts revealed that: (i) runway-only displays (*M* = -.851 sec, *SE* = .404 sec) produced greater TTC underestimates than runway-dot displays (*M* = -.357 sec, *SE* = .436 sec) (p < .05); and (ii) TTC estimates for runway-dot displays did not differ from those for dot-only displays (*M* = .068 sec, *SE* = .519 sec) (p > .05). The main effect of Glideslope was also found to be significant, $F(1.112, 20.017) = 55.388$, $p < .0001$. TTCs for 3 degree glideslopes were underestimated (*M* = -1.934 sec, *SE* = .302 sec), TTCs for 9 degree glideslopes were overestimated (*M* = .805 sec, *SE* = .579 sec) and TTCs for 6 degree glideslopes were relatively unbiased (*M* = -.012 sec, *SE* = .470 sec). A highly significant main effect was also found for Simulated TTC, $F(1.015, 18.278) = 82.354$, $p < .0001$. TTC estimates for the 4.02 sec (*M* = 1.595 sec, *SE* = .245 sec) and 6.52 sec (*M* = 1.058

sec, *SE* = .360 sec) Simulated TTC conditions were generally overestimated and TTCs for the 14.01 sec condition were underestimated (*M* = -3.794 sec, *SE* = .775 sec).

The interaction between Texture and Simulated TTC was also found to be significant, $F(1.923, 34.607) = 12.075$, $p < .0001$. Bonferroni post-hoc contrasts revealed that while increasing the simulated TTC from 4.02 to 6.52 sec did not significantly affect the TTC errors for dot-only and runway-dot displays ($p > .05$), the errors produced by runway-only displays were significantly reduced ($p < .05$).

A two-way interaction between Texture and Glideslope was also found to be significant, $F(2.956, 53.206) = 6.730$, $p < .001$ (see Figure 2). This interaction appears to have been driven by the following: (i) underestimates were larger for both runway-only and runway-dot displays than for dot-only displays in 3 degree glideslope conditions; (ii) overestimates were slightly larger for runway-dot and dot-only displays than for runway-only displays in 9 degree glideslope conditions; and (iii) Runway-dot displays produced near perfect estimates in 6 degree glideslope conditions, while dot-only displays were overestimated and runway-only displays were underestimated.

<INSERT FIGURE 2 ABOUT HERE>

Although the main effect of Aimpoint was not significant, $F(1, 18) = .810$, $p < .4$, a two-way interaction between Aimpoint and Glideslope was highly significant, $F(1.203, 21.653) = 22.100$, $p < .0001$ (see Figure 3). Mean TTC overestimates (9 degree glideslopes) and underestimates (3 degree glideslopes) were greater in displays with only an implicit aimpoint as compared to those with an explicit aimpoint. Estimated TTC in the explicit and implicit aimpoint conditions differed significantly in the 3 degree glideslope conditions ($p < .0001$) and approached significance in the 9 degree glideslope conditions ($p < .08$).

<INSERT FIGURE 3 ABOUT HERE>

Discussion

Since the glideslope biases in these TTC judgments appeared to be consistent with the previous glideslope biases in heading judgments reported by Palmisano and Gillam (2005), it was possible that TTC errors in the current experiment were due to observers misperceiving the heading simulated by our displays. Consistent with this notion, the inclusion of an explicit aimpoint in displays was found to reduce TTC error, suggesting that participants were able to more accurately estimate TTC when the true heading was known. However, contrary to the notion that TTC estimates were based on $R\tau_G$ or $R\tau_L$(1), 3 degree glideslope conditions were substantially underestimated, even when the display contained an explicit aimpoint. This finding opposes Mulder et al.'s (2000) assertion that $R\tau_G$ is accessed along the aiming line during the oblique approach towards a planar surface. Rather, the current results suggest that even when an explicit aimpoint was provided, TTC was not accessed from the aiming line. Contrary to the proposals of Grosz et al. (1995) and Mulder et al. (2000), this result cannot be attributed to variations in simulated sink-rate since the simulated sink-rates in the current experiment were equivalent for all glideslopes at each simulated TTC condition.

It was also predicted that TTC estimates would be more accurate or less biased as the density of the available display texture increased. This hypothesis was only partially supported. TTC judgments were in general less biased for the denser runway-dot and dot-only displays than they were for the runway-only displays. Since runway-dot displays contained the largest number of texture elements, it was anticipated that TTC estimates would be most accurate for this texture type. However, runway-dot displays did not produce significantly different TTC errors to dot-only displays. This finding was inconsistent with those of Palmisano and Gillam (2005) and Mulder et al. (2000), who found that the addition of ground texture information to a runway outline improved heading perception and promoted a higher percentage of successful simulated landings, respectively.

Finally, it was observed that the variability in responding to the 14.01 sec TTC simulation conditions was quite large across all glideslopes (relative to the 4.02 and 6.52 sec conditions). These results are not entirely controversial, as increases in both variability and inaccuracy tend to occur in PM tasks where the simulated TTC period increases (Tresilian, 1995). However, it is unlikely that the high variability in

14.01 sec simulations was responsible for the observed effect of glideslope on response bias - since the same glideslope effect was found for each of the simulated TTC conditions examined.

So in conclusion, and contrary to the proposition that TTC perception during an oblique night approach is based on $R\tau_G$ or $R\tau_L^{(1)}$, Experiment 1 revealed that TTC estimates were significantly affected by the simulated glideslope. Experiment 2 investigates two possible explanations for this glideslope effect on TTC judgments.

Possibility 1: The Area of Expansion Hypothesis. The relative amount of visible texture above and below the aiming line in the current displays was determined by the aimpoint location, which differed for each glideslope condition. During the stimulus exposure period, the greatest area of optical expansion occurred below the aiming line in 3 degree glideslope displays, and above the aiming line in 9 degree glideslope displays. The location of the aimpoint in 6 degree glideslope displays provided relatively balanced areas of optical expansion above and below the aiming line. As previously noted, the use of $\tau_L^{(2)}$ promotes erroneous TTC estimation during the oblique approach. If participants had utilized $\tau_L^{(2)}$, then it is possible that: (i) TTCs for 3 degree glideslopes were underestimated because the greatest area of optical expansion was below the aiming line (faster expansion); (ii) TTCs for 9 degree glideslopes were overestimated because the greatest area of optical expansion was above the aiming line (slower expansion); and (iii) TTCs for 6 degree glideslopes were estimated accurately because the expansion was more evenly distributed above and below the aiming line.

Possibility 2: The Indirect Calculation Hypothesis. One other possible explanation for the glideslope response bias found in Experiment 1 was that TTC might have been accessed indirectly, rather than directly via tau. Participants might have estimated TTC based on both the perceived angular approach velocity and perceived angular distance to the aimpoint. TTC estimation errors could have resulted from the systematic misperception of either the approach velocity, the distance to the aimpoint, or both of these factors. For example, the angular distances to the aimpoint were always 570.38 m for 3 degree glideslopes, 285.59 m for 6 degree glideslopes and 188.47 m for 9 degree glideslopes. Thus, the observed glideslope effect might have arisen if participants underestimated the longer distances (3 degree glideslopes) and overestimated shorter distances (9 degree glideslopes).

EXPERIMENT 2

Experiment 2 attempted to evaluate whether participants either utilize tau based on dominant area of expansion or calculate TTC indirectly (based on the perceived velocity of their simulated self-motion and their perceived distance to the aimpoint). Three different aimpoint locations were examined. The near aimpoint condition produced a greater area of expansion above the aiming line for all levels of glideslope (similar to 9 degree glideslope displays in Experiment 1). The middle aimpoint condition produced a relatively balanced expansion above and below the aiming line for all levels of glideslope (similar to 6 degree glideslope displays in Experiment 1). The far aimpoint condition produced a greater area of expansion below the aiming line for all levels of glideslope (similar to 3 degree glideslope displays in Experiment 1). If participants were biased towards expansion information from a dominant area in Experiment 1, then TTC biases in Experiment 2 should coincide with the dominant area of expansion independently of the glideslope condition (i.e. they should be determined by aimpoint location, not simulated glideslope).

To examine the indirect calculation hypothesis, the angular distance to the aimpoint was held constant for all of the aimpoint locations and glideslopes examined in Experiment 2 (by altering the simulated altitude at the start of the display). If the glideslope effect in Experiment 1 was due to participants misperceiving the near and/or far distances to the aimpoint by different amounts, then no differences in estimated TTC should occur between glideslopes or aimpoint location conditions in Experiment 2.

Method

Participants. Participants were 25 undergraduate students from the University of Wollongong (21 female, 4 male) volunteering in exchange for course credit. The ages of these non-pilots ranged from 18 to 27 years (*M* = 19.8 years). All reported normal or corrected-to-normal vision. All participants provided the experimenter with written informed consent before commencing the experiment.

Visual Displays. Unlike Experiment 1, displays always simulated an oblique approach towards a green runway outline only (simulated dimensions were identical to those used in Experiment 1). The simulated glideslopes for each display were 3, 6 or 9 degrees. Each display contained an explicit aimpoint at one of three locations from the near runway threshold: near (8.85 m; largest optical area above the aiming line), middle (256.02 m; relative balance between optical areas above and below the aiming line), and far (418.85 m; largest optical area below the aiming line). Angular approach velocities were 113.62 m/sec, and 75.85 m/sec, generating the two TTC conditions of 4.02 sec and 6.52 sec, respectively[2]. As the angular distance to the aimpoint was consistent across glideslope conditions (570.38 m), the simulated starting height and sink-rate increased with an increase in glideslope. $R\tau_G$ and $R\tau_L^{(1)}$ remained equal across all glideslope and aimpoint location conditions per simulated TTC condition.

Procedure. Trial blocks were organized by aimpoint location condition (near, middle, far). The order of these three blocks was randomly allocated. Participants were exposed to 4 repetitions of each simulated TTC variable (4.02 sec, 6.52 sec), per glideslope (3, 6, and 9 degrees) totaling 24 trials per block. Each trial block was administered twice, totalling 144 trials overall. Experiment 2 utilised the same PM task methodology employed in Experiment 1. Participant instructions and experimental procedures were similar to those of Experiment 1 (participants first observed the three automated exposure blocks prior to the experiment to familiarize them with the procedure and display characteristics).

Results

The data from five participants was excluded due to inconsistent responding. A 3 (Aimpoint Location) x 2 (Simulated TTC) x 3 (Glideslope) repeated measures analysis of variance (ANOVA) was performed on the TTC error data (α = .05). Importantly, both the main effects of Aimpoint Location ($F(2, 38) = 1.674$, $p = .201$) and Glideslope ($F(2, 38) = 1.808$, $p = .178$) failed to reach significance in this experiment. However, the main effect of Simulated TTC condition was significant, $F(1, 19) = 10.435$, $p < .004$, with 4.02 sec simulated TTC conditions being slightly underestimated (M = -.064 sec, SE = .399sec) and 6.52 sec conditions being slightly overestimated (M = .099 sec, SE = .390 sec). The interaction between Glideslope and Simulated TTC was significant, $F(2, 38) = 3.468$, $p < .041$ (see Figure 4). Bonferroni adjusted post-hoc contrasts indicated that TTC errors for 9 degree (but not for 3 or 6 degree) glideslope conditions increased significantly as the simulated TTC increased from 4.02 to 6.52 sec ($p < .001$). No further significant interaction effects were found.

<INSERT FIGURE 4 ABOUT HERE>

Discussion

The dominant area of expansion hypothesis was not supported, as there were no significant differences in the TTC errors for the three aimpoint location conditions. This suggests that participants did not estimate TTC based on either $\tau_L^{(2)}$ or the dominant optical area of expansion of the runway (i.e. above or below the aiming line). The prediction that the glideslope bias effect would disappear when the distance to the aimpoint remained constant was supported (for all levels of glideslope and aimpoint location). The increased accuracy of the results in Experiment 2 could also be interpreted as supporting the utilization of $R\tau_G$ or $R\tau_L^{(1)}$,however, this explanation appears unlikely considering that $R\tau_G$ and $R\tau_L^{(1)}$ were clearly not utilized in Experiment 1.

GENERAL DISCUSSION

The current experiments examined the effects of each of the following on TTC perception during simulated oblique approaches towards a ground plane: ground texture type, simulated TTC, simulated glideslope, simulated aimpoint location and simulated aimpoint type (explicit or implicit specification). The main purpose of this study was to compare the utility of $R\tau_G$ and

$R\tau_L^{(1)}$ cues when heading information was either explicitly or implicitly available. However, the results of Experiments 1 and 2 suggested that $R\tau_G$ and $R\tau_L^{(1)}$ were not the dominant cues used to estimate TTC in this situation.

In Experiment 1, the following glideslope biases were observed: TTC judgments were underestimated for 3 degree glideslopes and overestimated for 9 degree glideslopes. In the absence of an explicit aimpoint, it was possible that these TTC errors were produced by participants misperceiving the heading simulated by the display. However, contrary to the notion that heading misperception was responsible for these errors, significant TTC underestimation was still found when the 3 degree glideslope displays contained an explicit aimpoint. Hence, it was concluded that the restricted tau cues were not sufficient to accurately determine TTC in this experiment (even when explicit heading information was available).

Importantly, the glideslope bias found in Experiment 1 did not persist in Experiment 2. The main difference between these two experiments was that in Experiment 1 the simulated aimpoint distance varied with the glideslope, whereas in Experiment 2 the simulated aimpoint distance was identical for all glideslopes. Further, there was some evidence that the perceived angular approach velocity might also have influenced TTC estimates – with faster velocity (i.e. longer simulated TTC) conditions leading to TTC underestimation and slower velocity (i.e. shorter simulated TTC) conditions leading to TTC overestimation when the simulated glideslope was 9 degrees.

Taken together, these results appear to provide strong support for the indirect calculation of TTC.

According to this account, the glideslope bias found in Experiment 1 could have been produced by either the aimpoint distance, the angular approach velocity, or both variables being systematically misperceived by different amounts in each of the glideslope conditions. Because the simulated aimpoint distances were different for each glideslope condition in Experiment 1, they could have resulted in different degrees of speed/distance misperception. However, because the simulated aimpoint distances were held constant in Experiment 2, each glideslope condition should have produced a constant magnitude of error.

Recently, the notion that TTC judgments can be significantly influenced by non-tau based information has received support from a variety of studies. This research has provided evidence that TTC estimates/judgments depend on perceived velocity (e.g. Andersen, Cisneros, Atchley, & Saidpour, 1999; Smeets, Brenner, Trebuchet, & Mestre, 1996), perceived distance and/or depth order (DeLucia, 1991; DeLucia et al, 2003). Furthermore, it has been shown that the speed of simulated self-motion can be increased by up 50 percent (over a 0.5 sec period) prior to the detection of any change in perceived velocity (Monen & Brenner, 1994). Consistent with the account outlined above, this finding suggests that indirect calculations of TTC based on participant perceptions of approach velocity would be highly susceptible to error. To clarify this issue, future research could attempt to correlate participant perceptions of aimpoint distance and approach velocity (as individually measured variables) with their TTC estimates.

The high inter-subject variability in responses for both Experiments 1 and 2 suggests that TTC estimates may be unacceptably imprecise in simulated night landing situations (especially if only a runway outline is available). However, pilot skill in controlling the flare maneuver might sufficiently compensate for such high variability in real-world situations. Although the present experiments suggest that $R\tau_G$ and $R\tau_L^{(1)}$ did not dominate TTC judgments during our night landing simulations, this does not preclude their utility during shorter simulated TTC intervals. However, reducing the simulated TTC below 4.02 sec to verify this would limit the generalizability of any such research to the landing situation (in that it would not allow sufficient time to initiate the flare maneuver).

Applications

Several studies have found that actual aircraft landings performed under monocular viewing conditions (where pilot perceptions of distance may be reduced/impaired) were as accurate as those performed under binocular viewing conditions (e.g. Grosslight et al 1978; Lewis & Krier 1969; Lewis et al 1973). Some researchers have interpreted these findings as indicating that visual aircraft control during landing is based on direct perception. If this is the case then flare timing (based on $R\tau_G$, $R\tau_L$(1) or τ_L(2)) should be unaffected by misperceptions of environmental distance and aircraft speed. However, the current study has shown that TTC estimates can be altered dramatically by changing the simulated glideslope and/or distance to the aimpoint (even when the simulated TTC is held constant). These findings have important implications for flight simulation. Flare timing based on indirect TTC perception should result in systematic errors when pilots/trainees use entry-level flight simulators – as simulated distance can be dramatically misperceived when such displays are not collimated (Pierce et al, 1998).

Since TTC estimates improved with the inclusion of an explicit aimpoint, future research might examine alternative ways to illuminate the runway that are more conducive to safer night landing. Specifically, research might investigate runway illumination that allows the pilot to visually “lock on” to a specific aiming target upon descent. The inclusion of an explicit aimpoint in pilot training simulators may therefore provide a simple and cost effective means of improving night landings, with a further view towards implementation on existing tarmacs.

Conclusions

The current findings are consistent with previous research suggesting that the runway outline does not provide adequate information for night landing (e.g. Mertens, 1978, 1981). TTC estimates in our study were shown to be biased by altering the simulated glideslope and the simulated distance to the aimpoint. These findings were more consistent with indirect (as opposed to direct) perception of landing flare initiation. That is, participants estimated TTC based on perceived distance to the aimpoint and their instantaneous approach speed (as opposed to directly perceiving TTC based on $R\tau_G$, $R\tau_L^{(1)}$ or $\tau_L^{(2)}$). While we acknowledge that our night-time landing display conditions and passive timing task may have forced participants to favour an indirect strategy over a direct strategy, the present findings provide evidence of the important role that distance perception plays in the control this very difficult flight maneuver.

ACKNOWLEDGEMENTS

The research reported here was supported by Grant B2005/0119 from the Australian Transport Safety Bureau.

REFERENCES

Andersen, G. J., Cisneros, J., Atchley, P., & Saidpour, A. (1999). Speed, size, and edge-rate information for the detection of collision events. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 256-269.

Benbassat, D., & Abramson, C. I. (2002). Landing flare accident reports and pilot perception analysis. *The International Journal of Aviation Psychology, 12*, 137-152.

Bootsma, R. J., & Craig, C. M. (2003). Information used in detecting upcoming collision. *Perception, 32,* 525-544.

DeLucia, P. R. (1991). Pictorial motion-based information for depth perception. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 738-748.

DeLucia, P. R., & Meyer, L. E. (1999). Judgments about the time to contact between two objects during simulated self-motion. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1813-1833.

DeLucia, P.R., Kaiser, M.K., Bush, J.M., Meyer, L.E., & Sweet, B.T. (2003). Information integration in judgments of time-to-contact. *The Quarterly Journal of Experimental Psychology*, *56A*, 1165-1189.

Flach, J. M., & Warren, R. (1995). Low-altitude flight. In, J. M. Flach, P. A. Hancock, J. K. Caird, & K. J. Vicente (Eds.). *Local applications of the ecological approach to human-machine systems* (pp. 65-103). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gibson, J. J. (1950). *The perception of the visual world.* Cambridge, MA: Houghton Mifflin.

Gibson, J. J., Olum, P., & Rosenblatt, F. (1955). Parallax and perspective during aircraft landings. *American Journal of Psychology, 68,* 372-385.

Gray, R., & Regan, D. (2000). Do monocular time-to-collision estimates necessarily involve perceived distance? *Perception, 28,* 1257-1264.

Grosslight, J. H., Fletcher, H.J., Masterton, B. & Hagen, R. (1978). Monocular vision and landing performance in general aviation pilots: Cyclops revisited, *Human Factors*, *20*, 27-33.

Grosz, J., Rysdyk, R. T., Bootsma, R. J., Mulder, J. A., Vaart, J. C. van der, & Wieringen, P. C. W., van. (1995). Perceptual support for timing of the flare in the landing of an aircraft. In, J. M. Flach, P. A. Hancock, J. K. Caird, & K. J. Vicente (Eds.). *Local applications of the ecological approach to human-machine systems* (pp. 104-121). Hillsdale, NJ: Lawrence Erlbaum Associates.

Hancock, P. A., & Manser, M. P. (1997). Time-to-contact: More than tau alone. *Ecological Psychology, 9*, 265-297.

Hecht, H., Kaiser, M. K., Savelsbergh, G. J. P., & Kamp, J. van der. (2002). The impact of spatiotemporal sampling on time-to-contact judgments. *Perception and Psychophysics, 64,* 650-666.

Kaiser, M. K., & Mowafy, L. (1993). Optical specification of time-to-passage: Observers’ sensitivity to global tau.

Journal of Experimental Psychology: Human Perception and Performance, 19, 1028-1040.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5,* 437-459.

Lewis, C. E., & Krier, G. E. (1969). ‘Flight research program XVI: Landing performance in a jet aircraft after loss of binocular vision’, *Aerospace Medicine*, *40*, 957-963.

Lewis, C. E., Blakeley, R. W., Masters, R.L., & McMurty, T.C. (1973). Landing performance by low-time private pilots after the sudden loss of binocular vision – Cyclops II’, *Aerospace Medicine*, *44*, 1241-1245.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of time-to-contact. *Ecological Psychology, 8*, 71-99.

Mertens, H. W. (1978). Perceived orientation of a runway model in nonpilots during night approaches to landing. *Aviation, Space, and Environmental Medicine, 49,* 457-460.

Mertens, H. W. (1981). Perception of runway image shape and approach angle magnitude by pilots in simulated night landing approaches. *Aviation, Space, and Environmental Medicine, 52,* 373-386.

Monen, J., & Brenner, E. (1994). Detecting changes in one’s own velocity from optic flow. *Perception, 23,* 681-690.

Mulder, M., Pleijsant, J., Vaart, H., van der, & Wieringen, P. van. (2000). The effects of pictorial detail on the timing of the landing flare: Results of a visual simulation experiment. *The International Journal of Aviation Psychology, 10,* 291-315.

Palmisano, S., & Gillam, B. (2005). Visual perception of touchdown point during simulated landing. *Journal of Experimental Psychology: Applied, 11*, 19-32.

Pierce, B. J., Geri, G. A., & Hitt, J. M. (1998). Display collimation and the perceived size of flight simulator imagery. *Raytheon Training and Services.* Mesa: Arizona (Report Number: A904953).

Regan, D., & Grey, R. (2000). Visually guided collision avoidance and collision achievement. *Trends in Cognitive Sciences, 4*, 99-107.

Schiff, W., & Oldak, R. (1990). Accuracy of judging time to arrival: Effects of modality, trajectory, and gender. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 303-316.

Smeets, J. B. J., Brenner, E., Trebuchet, S., & Mestre, D. R. (1996). Is judging time-to-contact based on ‘tau’? *Perception, 25,* 583-590.

Tresilian, J. R. (1991). Empirical and theoretical issues in perception of time to contact. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 865-876.

Tresilian, J. R. (1993). Four questions of time to contact: a critical examination of research on interceptive timing. *Perception, 22,* 653-680.

Tresilian, J. R. (1995). Perceptual and cognitive processes in time-to-contact estimation: Analysis of prediction-motion and relative judgment tasks. *Perception and Psychophysics, 57*, 231-245.

Warren, W. H. *Jr.* (1995). Self-motion: Visual perception and visual control. In, W. Epstein, & S. Rogers (Eds.), *Handbook of perception and cognition: Perception of space and motion* (2nd ed.) (pp. 263-324). San Diego, California: Academic Press.

Figure Captions

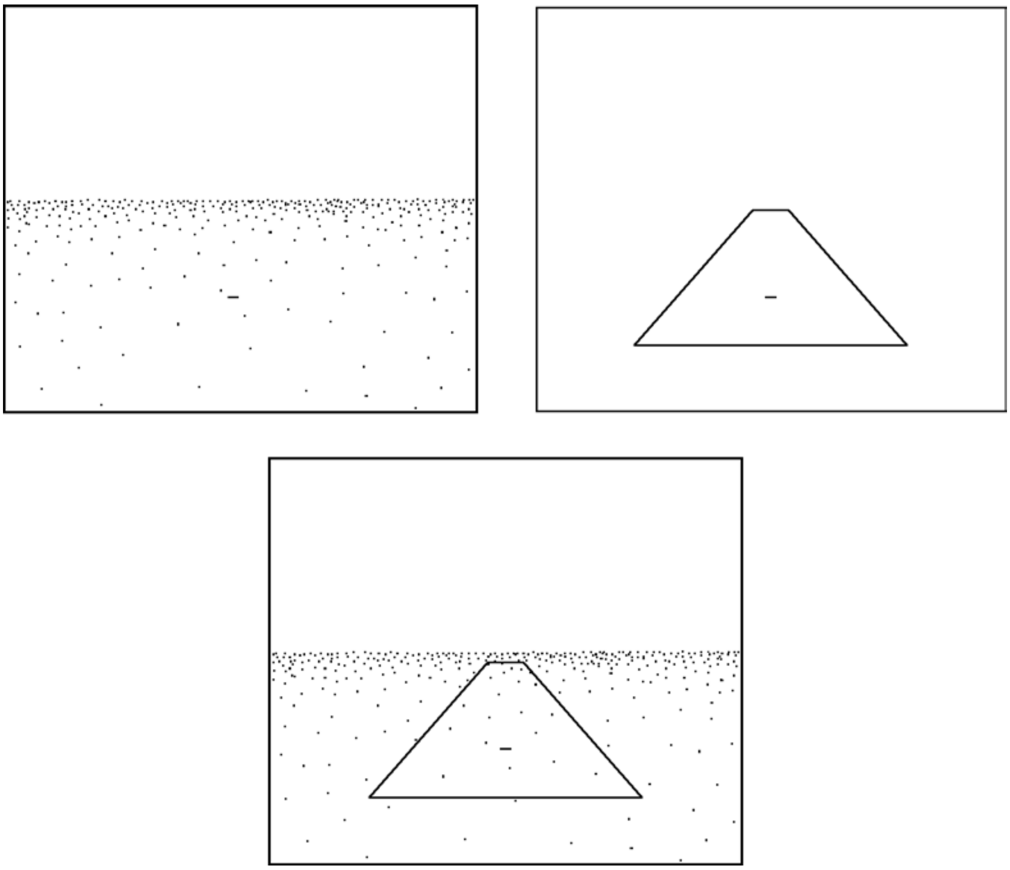

Figure 1. Display textures including demarked aimpoint. (A) dot-only; (B) runway-only, and; (C) runway-dot.

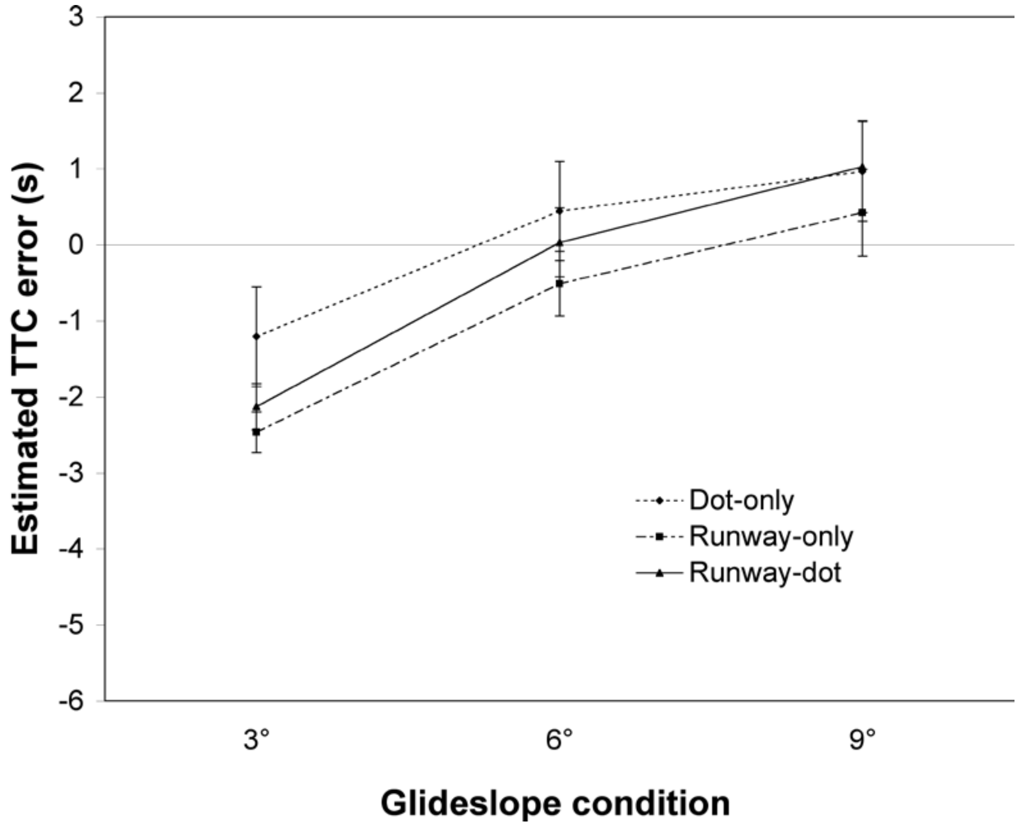

Figure 2. Mean estimated TTC for each texture type for each level of glideslope [Experiment 1]. Error bars indicate standard error.

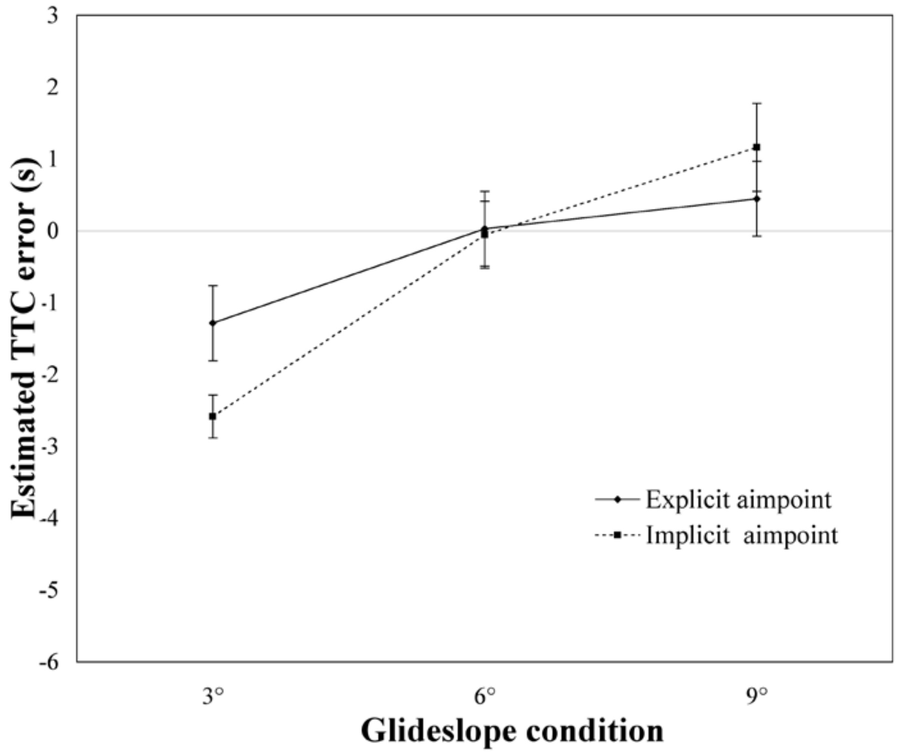

Figure 3. Mean estimated TTC for each level of aimpoint for each level of glideslope [Experiment 1]. Error bars indicate the standard error.

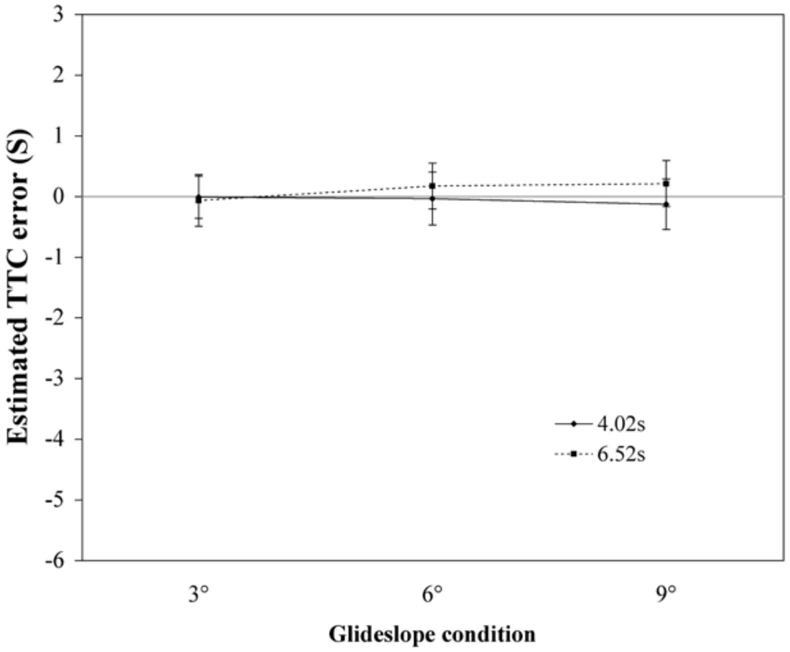

Figure 4. Mean estimated TTC for each glideslope condition for each level of simulated TTC [Experiment 2]. Error bars indicate the standard error.

Acknowledgments.

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FOOTNOTES

[1]Previous studies have examined flare timing performance with dynamic landings tasks and provided performance feedback (e.g. Grosz et al, 1995; Mulder et al, 2000). While there are many benefits to be gained from these more ecological landing tasks, it can prove difficult to ascertain how much of the flare error was due to perception and how much was due to control issues (in the case of the latter source of error, performance will be affected by differences in practice/experience, technique and other higher level cognitions).

[2]Large glideslope biases were found for all 3 of the simulated TTC conditions examined in Experiment 1. While the elimination of the 14.01 sec condition should have improved the overall accuracy and reduced the variability in responses for Experiment 2, it should not have removed the glideslope bias found in Experiment 1.