Approaching threatening stimuli cause an expansion of defensive peripersonal space

Neuro Forum on:

Bisio A, Garbarini F, Biggio M, Fossataro C, Ruggeri P, Bove M (2017) Dynamic shaping of the defensive peripersonal space through predictive motor mechanisms: when the “near” becomes “far.” J Neurosci 2017 37:2415-2424.

R.J. Bufacchi[1,2]

[1]Department of Neuroscience, Physiology and Pharmacology,
University College London (UCL), London, WC1E 6BT, UK;
[2]Centre for Mathematics and Physics in the Life Sciences and EXperimental biology (CoMPLEX),
University College London, London, WC1E 6BT, UK.

Corresponding author:
Rory John Bufacchi
Department of Neuroscience, Physiology and Pharmacology
University College London
Gower Street, WC1E 6BT London
rory.bufacchi.11@ucl.ac.uk
+44(0)7590267731

Keywords: defense, blink reflex, peripersonal space, movement

Abstract

When sudden environmental stimuli signalling threat occur in the portion of space surrounding the body (defensive peripersonal space), defensive responses are enhanced. Recently Bisio et al. (2017) showed that a marker of defensive peripersonal space, the defensive hand-blink reflex (HBR), is modulated by the motion of the eliciting threatening stimulus. These results can be parsimoniously explained by the continuous monitoring of environmental threats, resulting in an expansion of DPPS when threatening stimuli approach.

The closer a threatening stimulus occurs to a body part, the more likely it is to cause damage, and the stronger the elicited defensive responses become. The region of space surrounding the body in which this increase in defensive response occurs is termed defensive peripersonal space (DPPS; Graziano and Cooke, 2006). Its neural substrates in non-human primates likely consist of a parieto-premotor network. This network involves multisensory neurons in the ventral intraparietal area (VIP) and in the polysensory zone of area F4 (Cooke and Graziano, 2004; Cléry et al., 2014). In humans, the DPPS surrounding the face has been described by recording the enhancement of the defensive blink reflex elicited by electrical stimulation of the hand (hand-blink reflex; HBR) when the hand is nearer to the face compared to when it is far (Sambo et al., 2012). The DPPS has been suggested to have the shape of a bubble elongated asymmetrically along the rostro-caudal axis, extending further above eye-level (Bufacchi et al., 2016).

In a recent paper, Bisio et al. (Bisio et al., 2017) delivered the stimuli to elicit the HBR while participants moved their hand. They instructed participants to make a single hand movement towards and then away from their face (or vice-versa) roughly every 30 seconds, and stimulated the hand at one of six time-points during this motion. They reported that HBR magnitude was affected by this hand movement when the hand was *near* the face: in that position, when the hand was moving *away* from the face, the HBR magnitude was *decreased* compared to when the hand was moving towards the face (Figure 1, panel A, left). In contrast, HBR magnitude was not dependent on movement direction when the hand was in the other two positions farther from the face. Remarkably, they showed a similar effect when participants imagined moving their hand, but did not actually perform the movement. They provided a convincing directional interpretation: the HBR magnitude in the near positions can be reduced by a movement of the threat away from the body part that needs to be defended. The dependence of HBR magnitude on movement was also suggested by the results of Wallwork et al. (2106), which, however, consisted in a seemingly opposite pattern: where Bisio et al. reported an HBR decrease at the near position when the hand was moving away from the face, Wallwork at al reported no difference between movement directions at the near position. Furthermore, Wallwork et al reported an HBR increase at the far position when the hand was moving towards the face, while Bisio et al. reported no difference between movement conditions at that position (Figure 1, panel A, left). Both articles suggest that the cause for the observed effects might be the ability of the nervous system to predict the future location of the hand. However, their two explanations are opposite: in Bisio et al. the prediction of where the hand is going to be is assumed to cause a down-regulation of HBR magnitude but not an up-regulation, while in Wallwork et al. it is assumed to cause an up-regulation of HBR magnitude, but not a down-regulation.

A simple explanation could reconcile these two seemingly opposite observations, which could in fact be instances of the same physiological phenomenon. This explanation is that the DPPS size is not stationary, but changes depending on the context: it increases when threatening stimuli move toward an endangered body area. Interestingly, this notion is present in the title of the article by Bisio et al., but not further elaborated on. Considering the wider body of work on peripersonal space (not only in relation to defence) provides support for this explanation. It has been shown that the size of peripersonal space is malleable within subject (Farnè et al., 2016). For example, tool use reshapes action space around the tool (Longo and Lourenco, 2007), walking expands peripersonal space forward (Noel et al., 2014), and gravitational cues warp the size of defensive peripersonal space (Bufacchi and Iannetti, 2016). Even more interestingly, the firing rate of the cells thought to underlie the DPPS specifically is not only dependent on the stimulus position, but also on its movement direction and its speed: these cells generally fire more when (1) the stimulus moves towards the body, and (2) it moves faster (Graziano and Cooke, 2006).

Unfortunately, Bisio et al. did not discuss this possibility, and instead assumed the opposite, namely that the DPPS is of fixed size (Figure 1, panel A, right). This reasoning led to the conclusion that '*… these findings might be explained as a down-regulation of the HBR response when planning to move far from the face, albeit the hand was <u>inside</u> the defensive peripersonal space'*. In other words, they claimed that when the hand is moving away from the face, the HBR is down-regulated to baseline levels, *even though it is inside the DPPS of the face*. This reasoning seems inconsistent with the definition of the DPPS as the zone within which the HBR magnitude exceeds a specific threshold.

That the DPPS is malleable is consistent with its survival advantage: the probability that a threat will hit the face is higher when the source of that threat (the stimulation on the wrist) is moving towards the face. This increased probability of hitting in turn increases the threat's potential for harm, and therefore necessitates a stronger HBR, to proportionally match the increased danger of the threat (Bufacchi et al., 2016). Under this framework, the HBR increase that Bisio et al observed at the nearest position when the hand is moving towards the face can be interpreted as an *expansion* of DPPS. In other words, the DPPS expands from a size where it does not reach the nearest hand position from the face, to a size where it encompasses that nearest position (Figure 1, panel B, right). Similarly, the increase in HBR magnitude at the far position when the hand is moving toward the face observed by Wallwork et al (2016) would then be an *expansion* of DPPS to encompass that furthest position, from a size where the DPPS only encompassed the nearest position. Note that this line of reasoning makes the assumption that in Wallwork et al (2016) there is a ceiling effect: the HBR magnitude has a maximum value, and this value is reached at the near position. When the DDPS expands to encompass the furthest position, the HBR elicited when the hand is at that position also reaches the ceiling magnitude.

Even if this reasoning is correct, an important issue that remains to be solved is which DPPS measure Bisio et al considered as a baseline; Figure 1 shows that they tested the HBR magnitude under 3 conditions: while the hand was moving toward the face, away from it, and not moving at all. They took the *pattern* of HBR increase in the static condition as a baseline measure: in that condition, the HBR magnitude at the near position is larger than the HBR magnitude in the other two positions. They then reasoned that, because this pattern was present in the towards condition but not in the away condition, in this latter condition the expected hand position must have been outside the DPPS. Importantly, however, in the static condition, Bisio et al. measure an HBR *overall* much larger than in the two movement conditions. Therefore, using the static condition as a baseline measure of DPPS size is unlikely to be correct. In fact, the difference between static and moving conditions is most likely caused by expectation; in the moving conditions, subjects spent most of their time with the hand resting on a table, then moved it toward and away from their face once per trial when prompted by the experimenter. During this movement the shock was delivered when the forearm was at a specific angle. Therefore, as Bisio et al. also point out, participants knew that they could only possibly get a shock once they started moving. This expectation effect most likely resulted in participants linking the movement of their arm to the delivery of a shock, thereby decreasing the surprise and hence the threatening value of the shock.

Therefore, in *any* conditions where the subject's hand is moved, the baseline *size* of the DPPS might be decreased due to higher stimulus predictability. This would result in a smaller HBR magnitude difference between the near and far conditions, or even no difference at all if the baseline DPPS size were small enough. Therefore, a better baseline would have been a condition in which the participants trigger the shock, and wherein the shock occurs within ~4 seconds from the trigger (i.e., a similar temporal delay between when the participants began the movement, and when the shock occurred in Bisio et al 2017). If in this condition the HBR is equal in the nearest and the furthest hand positions (or at least is more similar in magnitude than when the hand is moving towards the face,), this would demonstrate that, when the stimulus is expected, the DPPS is smaller than the distance between the nearest hand position and the face. In this way, when the hand is moving toward the face, the DPPS size would increase from baseline, resulting in an increase in HBR magnitude at the nearest hand position. This explanation is also supported by the observation that baseline DPPS size (i.e. regardless of hand movement) is not substantially different from the condition in which the hand moves away from the face when the movement of the hand is not temporally linked to the stimulus onset (Wallwork et al., 2016).

Interpreting the results of the discussed studies within the framework of an expansion of DPPS emphasizes the proposed link between the activity of cortical areas underlying the spatial modulation of defensive responses (such as VIP and F4; Cooke and Graziano, 2004) and the brainstem circuits mediating the HBR (Sambo et al., 2012). Indeed, VIP neurons are highly selective to the direction and velocity of stimuli (Colby et al., 1993) and receive dense proprioceptive inputs (Lewis and Van Essen, 2000), while the receptive field of many F4 neurons expands in depth when the stimulus speed increases (Fogassi et al., 1996). Such response features would be necessary to cause an expansion of

DPPS in response to the movement of the forearm relative to the face. Accordingly, VIP has been proposed to subserve impact prediction (Cléry et al., 2015). These areas receive input from the superior collicus and pulvinar (Makin et al., 2012), both of which respond to looming stimuli and are involved in time-to-collision judgements (Billington et al., 2011). The superior colliculus is also strongly involved in enacting defensive responses across species (Pereira and Moita, 2016) and has multimodal response properties (Triplett et al., 2012). Interestingly therefore, it is possible that the brainstem circuits mediating the HBR might also be influenced by midbrain areas. Regardless of the exact anatomical origin of the HBR modulation, these observations also emphasise that even simple subcortical reflexes can be modulated in sophisticated manners by other brain areas. This important notion should be kept in mind when designing and interpreting experiments measuring even the most basic behavioural responses.

In conclusion, a parsimonious explanation of the results of Bisio et al. is that the DPPS size increases when the hand carrying the threatening stimulus is moving toward the face, following the estimated increase in probability that the moving threat will harm the face.

References

Billington J, Wilkie RM, Field DT, Wann1 JP (2011) Neural processing of imminent collision in humans. Proc R Soc B 278:1476–1481.

Bisio A, Garbarini F, Biggio M, Fossataro C, Ruggeri P, Bove M (2017) Dynamic Shaping of the Defensive Peripersonal Space through Predictive Motor Mechanisms: When the “Near” Becomes “Far.” J Neurosci 37:2415–2424.

Bufacchi RJ, Iannetti GD (2016) Gravitational cues modulate the shape of defensive peripersonal space. Curr Biol 26:R1133–R1134.

Bufacchi RJ, Liang M, Griffin LD, Iannetti GD (2016) A geometric model of defensive peripersonal space. J Neurophysiol 115:218–225.

Cléry J, Guipponi O, Odouard S, Wardak C, Hamed S Ben (2015) Impact Prediction by Looming Visual Stimuli Enhances Tactile Detection. J Neurosci 35:4179–4189.

Cléry J, Guipponi O, Wardak C, Ben Hamed S (2014) Neuronal bases of peripersonal and extrapersonal spaces, their plasticity and their dynamics: Knowns and unknowns. Neuropsychologia 70:313–326.

Colby CL, Duhamel JR, Goldberg ME (1993) Ventral intraparietal area of the macaque: anatomic location and visual response properties. J Neurophysiol 69:902–914.

Cooke DF, Graziano MS (2004) Super-flinchers and nerves of steel: defensive movements altered by chemical manipulation of a cortical motor area. Neuron 43:585–593.

Farnè A, Serino A, van der Stoep N, Spence C, Di Luca M (2016) Depth: the Forgotten Dimension. Multisens Res 29:1–32.

Fogassi L, Gallese V, Fadiga L, Luppino G, Matelli M, Rizzolatti G (1996) Coding of peripersonal space in inferior premotor cortex (area F4). J Neurophysiol 76:141–157.

Graziano MS, Cooke DF (2006) Parieto-frontal interactions, personal space, and defensive behavior. Neuropsychologia 44:845–859.

Lewis JW, Van Essen DC (2000) Corticocortical connections of visual, sensorimotor, and multimodal processing areas in the parietal lobe of the macaque monkey. J Comp Neurol 428:112–137.

Longo MR, Lourenco SF (2007) Space perception and body morphology: Extent of near space scales with arm length. Exp Brain Res 177:285–290.

Makin TR, Holmes NP, Brozzoli C, Farnè A (2012) Keeping the world at hand: rapid visuomotor processing for hand-object interactions. Exp brain Res 219:421–428.

Noel J-P, Grivaz P, Marmaroli P, Lissek H, Blanke O, Serino A (2014) Full body action Remapping of Peripersonal Space: The case of walking. Neuropsychologia.

Pereira AG, Moita MA (2016) Is there anybody out there? Neural circuits of threat detection in vertebrates. Curr Opin Neurobiol 41:179–187.

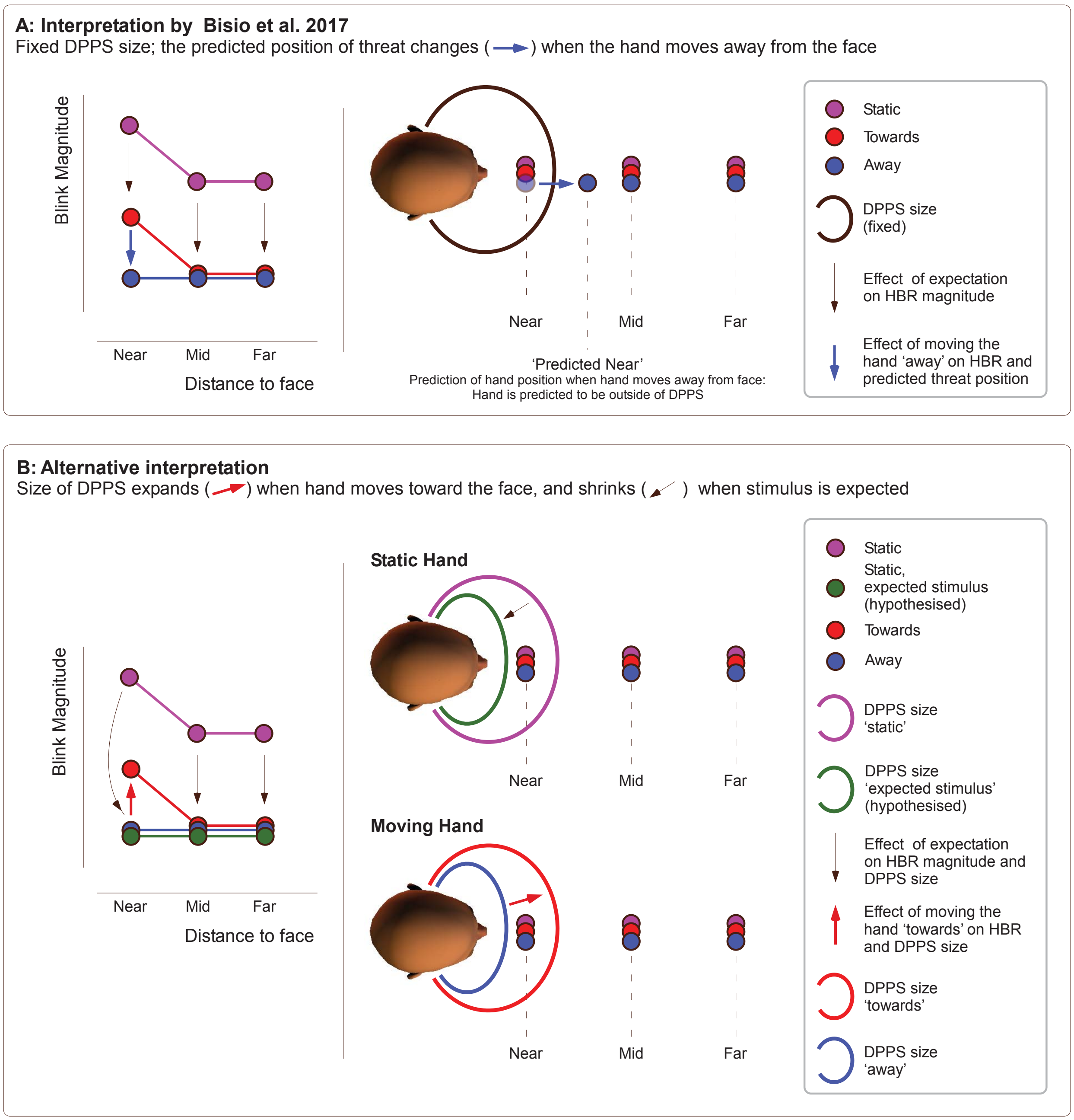
Sambo CF, Forster B, Williams SC, Iannetti GD (2012) To blink or not to blink: fine cognitive tuning of the defensive peripersonal space. J Neurosci 32:12921–12927.

Triplett JW, Phan A, Yamada J, Feldheim DA (2012) Alignment of multimodal sensory input in the superior colliculus through a gradient-matching mechanism. J Neurosci 32:5264–5271.

Wallwork SB, Talbot K, Camfferman D, Moseley GL, Iannetti GD (2016) The blink reflex magnitude is continuously adjusted according to both current and predicted stimulus position with respect to the face. Cortex 81:168–175.

Figure Legend

Figure 1. Schematic of hand movement effects on Hand-Blink Reflex (HBR) magnitude. Panel A: in the interpretation put forward by Bisio et al. (2017) the size of the Defensive Peripersonal Space (DPPS) is fixed. Left sub-panel: sketch of HBR magnitude across different conditions. Right sub-panel: assumed DPPS (black line) and predicted positions of the threat (coloured circles). In this interpretation, when (1) the threat is near the face and (2) it moves away from the face, the position of the threat is predicted to shift outside the DPPS (blue arrows in right sub-panel), with a consequent decrease in HBR magnitude at the near position (blue arrow in left sub-panel). In both conditions where the hand moves, the movement of the hand is linked to the stimulus onset, therefore causing an overall HBR magnitude decrease. Importantly, Bisio et al assume this ‘expectation effect’ to be equal at all hand positions (black arrows in left sub-panel). Panel B: an alternative interpretation is that the DPPS size is malleable. Left sub-panel: sketch of HBR magnitudes across different conditions, also including hypothetical real baseline magnitude when the eliciting shock is expected. Right sub-panel: implied size of DPPS (coloured lines) and predicted positions of the threat (coloured circles). In this alternative interpretation, when the threat moves towards the face, the DPPS expands (red arrow in right sub-panel), causing an increase in HBR magnitude at the near position (red arrow in left sub-panel). In this interpretation, the expectation effect results in both an overall HBR magnitude decrease and in a DPPS shrinkage (black arrows in both sub-panels). While both interpretations are plausible, only the alternative interpretation fits with prior empirical observations (e.g. Wallwork et al. 2016).


A: Interpretation by Bisio et al. 2017
Fixed DPPS size; the predicted position of threat changes ( ) when the hand moves away from the face
Blink Magnitude
Near
Mid
Far
Distance to face
Near
Mid
Far
'Predicted Near'
Prediction of hand position when hand moves away from face:
Hand is predicted to be outside of DPPS
Static
Towards
Away
DPPS size
(fixed)
Effect of expectation
on HBR magnitude
Effect of moving the
hand 'away' on HBR and
predicted threat position
B: Alternative interpretation
Size of DPPS expands ( ) when hand moves toward the face, and shrinks ( ) when stimulus is expected
Blink Magnitude
Near
Mid
Far
Distance to face
Static Hand
Near
Mid
Far
Moving Hand
Near
Mid
Far
Static
Static,
expected stimulus
(hypothesised)
Towards
Away
DPPS size
'static'
DPPS size
'expected stimulus'
(hypothesised)
Effect of expectation
on HBR magnitude and
DPPS size
Effect of moving the
hand 'towards' on HBR
and DPPS size
DPPS size
'towards'
DPPS size
'away'