Urbanisation, the Arousal System, and Covert and Overt Attentional Selection

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Highlights

- Urban exposure impacts the information processing style of human beings
- This change in style is expressed both in terms of attentional engagement (the deployment of mental processing resources, or covert attentional selection) and of visual exploration (eye movements, or overt attentional selection)
- Both these effects may be underpinned by lifestyle-driven variations in arousal-related processing
- Arousal variations may be linked to the neuromodulatory locus coeruleus-norepinephrine (LC-NE) system in the brain that is key to regulating cognitive function

Abstract

Urbanisation is growing rapidly. We review evidence that this growth is altering the default information processing style of human beings by impacting both overt and covert processes of attentional selection (i.e., attentional selection with and without eye movements respectively), in ways consistent with reduced attentional engagement and increased exploration. Whilst the factors and systems mediating these effects are likely to be many and various, we focus on one system which may be responsible for mediating effects on both covert and overt attentional selection. Specifically, the neuromodulatory locus coeruleus-norepinephrine (LC-NE) system is key to regulating cognitive function in a behaviourally-relevant and arousal-dependent manner and therefore well suited to supporting adaptation to the profound socio-ecological changes inherent in urbanisation.

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Urbanisation is growing rapidly: as of 2017, 55% of the world's population lived in an urban environment, compared to just 33% in 1960 [1]. Here we review evidence that this spread of urbanisation is altering the default information processing style of human beings by impacting both covert and overt processes of attentional selection, processes that involve respectively the orienting of mental processing resources, or the 'mind's eye', versus physical eye-movements. Whilst the factors and systems mediating these effects of urbanisation are likely to be many and various, we focus on one system which may be responsible for mediating effects on both covert and overt attentional selection, processes often explained by very different systems. This system is the neuromodulatory locus coeruleus-norepinephrine (LC-NE) system that is key to "regulating cognitive function in a behaviourally-relevant and arousal-dependent manner" (p.16) [2] and therefore well suited to supporting adaptation to the profound socio-ecological changes inherent in urbanisation.

In support of this account, we review evidence on the impact of urbanisation on a variety of populations from around the world including not just the "WEIRD" (white, educated, industrialised, rich, and democratic) [3] and other high-income populations that are usually reported in the cognitive literature but also populations from low- and middle-income countries that today comprise the majority of the world's population [4].

Covert Attentional Selection

Much of the growing interest in the cognitive impact of urbanisation can be traced back to the pioneering work of Kaplan [5] on Attention Restoration Theory (ART). According to this theory, inhabitants of urban environments are exposed to a plethora of stimuli that compete for their attention, only some of which are relevant to behavioural goals; remaining focused on relevant information exhausts directed attention processes which can however be restored by exposure to less stimulating natural environments. Compatible with this theory, Berman, Jonides and Kaplan [6] showed that when American participants either walked in nature or were shown pictures of nature both their attentional control (indexed using a flanker selective-attention task) and working memory (WM; indexed using a backwards digit-span task) improved compared to when they walked in an urban area or were shown pictures of urban environments.

The present authors and their colleagues extended this work to the traditional Himba – a non-WEIRD population from a remote part of northern Namibia – and showed that, compared to urban participants in Namibia and/or in the UK, the traditional Himba showed better attentional control: they showed (i) no significant distraction from a motion singleton previously reported always to capture attention [7] and (ii) focused spatial attention and reduced distractor interference on a flanker selection task of low perceptual load [8] which is widely assumed not to support attentional engagement and efficient selection [9,10] (although see Linnell and Caparos [11]). These findings extended previous suggestions by Jung that remote peoples are generally better at concentrating [12].

On the basis of these findings, Linnell et al [8] invoked the work of Aston-Jones on the dynamic control of attentional state [13] to argue that natural environments – on the one hand – promote the adoption of engaged attentional states that facilitate attentional control and performance of the task at hand while urban environments – on the other hand – promote the adoption of explorative states that facilitate non-selective processing of the diverse stimulation and opportunities they afford.

Linnell, Caparos, and Davidoff [14] drew still further on the work of Aston-Jones and colleagues by suggesting that this effect of urbanisation is mediated by the neuromodulatory LC-NE arousal system [15]. This system has been shown by Aston-Jones and colleagues to be key to modulating attentional state and cognitive function in keeping with behavioural demands and closely linked arousal-related processing [13,16]. Specifically, the LC ensures that middling amounts of arousal are associated with attentional engagement, while elevated arousal is associated with exploration, by increasing its tonic activity with increasing arousal.

Linnell et al [8,14] suggested that urbanisation provokes a shift in the LC-NE arousal system towards increased exploration and decreased engagement. This suggestion is in keeping with the association between urbanisation and stress [17,18] (for a review of the links between stress and LC activation, see Aston-Jones, Gonzalez, & Doran [19]). It is also in keeping with Broadbent's [20] suggestion that urban populations express higher levels of arousal and converging evidence for such differences between the traditional Himba and urban UK controls [14]. Such population differences open up the possibility that a widely reported (leftwards) spatial bias (pseudo-neglect [21,22]) - that has long been assumed to represent normal human functioning - may be the product of hyper-arousal in urban populations [14].

Urbanisation has also been shown to impact the anterior cingulate cortex and amygdala [17] which may, we suggest here, result in more complex, regulatory effects on the LC-NE arousal system. Once this possibility is taken into account our LC-NE arousal account may be able to subsume the directed-attention/WM capacity account of urbanisation [6]: recent work by Unsworth and Robison [23,24,25] suggests that the well-documented relation between attentional control and WM is partially underpinned by individual variation in the efficiency with which LC-NE functioning is regulated, so that if urbanisation impacts the efficiency with which the LC-NE system is regulated it will also affect attentional control and WM capacity as documented by Berman and colleagues.

Beyond covert selection, our LC-NE arousal account can also encompass effects of urbanisation on overt selection. We provide converging evidence for this in the next section.

It is worth noting at this juncture that effects on covert and overt selection are not generally studied in a common explanatory framework (although see Alotaibi, Underwood & Smith [26]).

Overt Attentional Selection

We argue here for the first time that work by Aston-Jones and colleagues on the LC-NE arousal system is compatible with arousal-related processing mediating the impact of urbanisation not just on the balance between exploratory and task-engaged styles in covert selection (as discussed in the previous section) but also in overt selection or eye-movement looking patterns.

According to Aston-Jones, Rajkowski, and Cohen [16], there is a close relationship between LC activity and eye movement looking patterns: "Decreased steady foveation [i.e., a decreased tendency to keep the eyes still at the onset of each trial], and increased 'scanning' eye movements, were associated with epochs of elevated LC activity [and], conversely, consistent visual fixation occurred during periods of intermediate LC discharge." [27] (p.1312). Others too have suggested that more exploratory looking patterns accompany higher levels of arousal/LC activity [28,29]. If in addition urbanisation promotes hyper-arousal, as suggested in the previous section, it is then a small step to suggest that it will make looking patterns – in terms of fixation durations and/or saccade lengths – more exploratory and, indeed, recent work from 2018 is compatible with this suggestion.

Specifically, Köster, Itakura, Yovsi, and Kärtner [30] compared looking patterns between 5-year-olds from rural populations in Cameroon (Africa) and from urban populations in Germany and Japan, during free viewing of pictures of figural objects. They showed that the rural Cameroonians looked significantly longer at figural objects than their urban counterparts, whose eye movements were more wide-ranging, encompassing more of the time the background or context against which the figural object was presented.

Particularly noteworthy was how much larger the differences in looking patterns were between the rural and urban populations, as compared to the differences between the two urban populations, the Germans and Japanese. The cross-cultural literature has explained differences in looking patterns between Western and East-Asian populations [31,32] using a social-organisation account [33,34]. According to this account, individualist versus collectivist cultures engender information processing styles that are respectively analytical versus holistic, promoting the selection of respectively figural versus background information (although see Rayner and colleagues [35]).

Yet, despite the social organisation of rural Cameroonians being more collectivist than that of either of the urban samples studied, the rural group was actually the one that showed the most focused looking-patterns. Thus, while social organisation is undoubtedly an important driver of looking patterns, the work of Köster et al [30] suggests that urbanisation can be a more important one. What we propose here is that this impact of urbanisation on overt selection may be at least partially mediated by the LC-NE arousal system, such that urbanisation promotes more exploratory looking behaviours.

The rural-urban differences in exploratory looking behaviours that are predicted by our LC-NE arousal-based account may explain rural-urban differences in susceptibility to the Ebbinghaus illusion: specifically, reduced susceptibility to this contextual size illusion has been reported in rural Cameroonians compared to both German and Japanese urban groups [30] and this finding replicates previous findings of reduced susceptibility in the traditional Himba compared to urban groups from the UK and Japan [36,37].

Reduced susceptibility to illusions such as the Ebbinghaus – which depend for their existence on the processing of irrelevant contextual information – is expected to go hand-in-hand with looking patterns that are focused on figural objects [30]. An arousal-based account, along the lines that the rural Cameroonians and remote Namibians are not hyper-aroused and make fewer (exploratory) eye movements, can potentially explain this finding given the link that exists between eye movements and illusion size: Mruczek and colleagues [38,39] have argued that eye movements create informational uncertainty about retinal-size and distance cues to size and thus increase the weighting of relational cues from irrelevant contextual information and, in so doing, augment the size illusion that is the Ebbinghaus.

Similarly, it is possible that an arousal-based account invoking differences in looking patterns can also explain the pattern of findings reported in a study of simultaneous lightness contrast (SLC) comparing traditional Himba participants with urban Himba and UK populations [40]. Specifically, this study involved comparative lightness judgements of pairs of grey target discs arrayed side by side, one on a white ground and the other on a black. While all groups showed SLC by over-estimating the lightness of the disc on the black ground, traditional Himba showed much increased SLC compared to the urban groups.

This finding is initially puzzling, especially in light of the generally more accurate judgements of the traditional Himba [36,37]; it could however be explained if the traditional Himba move their eyes less and consequently sample the black-white boundary between target grounds less [40], given that removal of this boundary increases SLC [41,42]. This suggestion is compatible with the close coupling that has been demonstrated between lightness judgements and the specific information selected by eye movements [43].

Conclusions and Future Directions

This brief review has provided evidence that through our creation of urban environments we are changing not just our environment but also our default information processing style and what we take from our environment. We suggest that the same neuromodulatory system, namely the LC-NE arousal system, may mediate effects of urbanisation on both covert and overt processes of information sampling by making them less task-focused and more exploratory, changes that are presumably adaptive to the more open-ended nature of urban living.

This is absolutely not, however, to suggest that the same parts of the LC-NE system mediate these effects of urbanisation, over the same timescales. The studies reviewed here suggest that the effects of urbanisation on covert selection can be quite dramatic, with urbanised Himba – who received a remote upbringing like that of the traditional Himba and only moved to a small town in early adulthood – showing covert attention that is indistinguishable from that of urbanised controls raised in and living in a city [8]. In contrast, the effects of urbanisation on overt selection in the studies reported here would seem to be less dramatic, with the urbanised Himba falling between the traditional Himba and UK controls in terms of their levels of susceptibility to the Ebbinghaus illusion [36] and levels of SLC [40].

Given that the effects of urbanisation on covert and overt selection appear to follow different timescales, it is likely that they are underpinned by different effects, perhaps occurring at different stages of development. Indeed, it is tempting to draw superficial parallels with the work of Meyer-Lindenberg and colleagues [17] showing that – at least under conditions of social stress – effects of *urban living* are underpinned by processing differences in the amygdala while effects of *urban upbringing* are underpinned by processing differences in the anterior cingulate cortex. The LC-NE arousal system is however highly interconnected with diverse brain regions and future work will be needed to elucidate the precise ways in which it may mediate the impact of urbanisation on covert and overt selection.

Future work will also be needed to understand what urbanisation actually means and what types of socio-ecological conditions result in the types of 'rural-urban' processing differences documented here. A recent study suggests that high population density may not be a sufficient predictor of at least some of the cognitive effects of urbanisation [44] and it may prove to be not even a necessary predictor in some of today's virtually networked populations. Other socio-ecological factors, such as the adoption of the fast-paced way of life that is associated with WEIRD and other high-income populations, may prove to be more critical predictors of the radical changes in processing style that accompany urbanisation.

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This study shows that, unlike Westerners, both rural and urban Rwandan participants present with a local bias on a similarity matching Navon task. It reveals effects of education and urban experience on local-global perceptual bias but suggests that differences in the impact of these variables on lifestyles around the world can result in profound differences in perceptual style, even between educated and urban populations.